



# Chemistry Live Complete Textbook in full

Organic Chemistry li - Lab (St Joseph's University)

## **Textbook – Worked Solutions**

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## Chapter 4 – The Periodic Table

### 4.1 (i)

In 100 atoms of gallium there are:

$$60 \text{ atoms of mass } 69 = 60 \times 69 = 4140$$

$$40 \text{ atoms of mass } 71 = 40 \times 71 = 2840$$

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$$\text{Total mass of 100 atoms} = 6980$$

$$\text{Average mass of 1 atom} = 69.8$$

Answer: Relative atomic mass of gallium = 69.8

### 4.5 (b) (iii)

In 100 atoms of copper there are:

$$70 \text{ atoms of mass } 63 = 70 \times 63 = 4410$$

$$30 \text{ atoms of mass } 65 = 30 \times 65 = 1950$$

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$$\text{Total mass of 100 atoms} = 6360$$

$$\text{Average mass of 1 atom} = 63.6$$

Answer: Relative atomic mass of copper = 63.6

## Chapter 9 - The Mole Concept

### 9.1

Since a sulfur atom ( $A_r = 32$ ) weighs twice as much as an oxygen atom ( $A_r = 16$ ), 32 g of sulfur atoms and 16 g of oxygen atoms both contain the same number of atoms.

Answer: 32 g

### 9.2

- (a) 1 mole of H atoms = 1 g  
 1 mole of  $H_2$  molecules =  $2 \times 1 = 2$  g.
- (b) 1 mole of N atoms = 14 g  
 1 mole of  $N_2$  molecules =  $2 \times 14 = 28$  g
- (c) 1 mole of O atoms = 16 g  
 1 mole of  $O_2$  molecules =  $2 \times 16 = 32$  g
- (d) 1 mole of Cl atoms = 35.5 g  
 1 mole of  $Cl_2$  molecules =  $2 \times 35.5 = 71$  g
- (e) 1 mole of F atoms = 19 g  
 1 mole of  $F_2$  molecules =  $2 \times 19 = 38$  g
- (f) 1 mole of Br atoms = 80 g  
 1 mole of  $Br_2$  molecules =  $2 \times 80 = 160$  g

### 9.3 NOTE Relative Molecular Mass has NO units!

(a) Relative Molecular Mass  $H_2SO_4 = (2 \times 1) + 32 + (4 \times 16)$   
 $= 2 + 32 + 64$   
 $= 98$

(b) Relative Molecular Mass  $CO_2 = 12 + (2 \times 16)$   
 $= 12 + 32$   
 $= 44$

(c) Relative Molecular Mass  $HI = 1 + 127$   
 $= 128$

(d) Relative Molecular Mass  $NaCl = 23 + 35.5$   
 $= 58.5$

(e) Relative Molecular Mass  $AlBr_3 = 27 + (3 \times 80)$   
 $= 27 + 240$   
 $= 267$

(f) Relative Molecular Mass  $SO_2 = 32 + (2 \times 16)$   
 $= 32 + 32$   
 $= 64$

$$\begin{aligned} \text{(g) Relative Molecular Mass CuCO}_3 &= 63.5 + 12 + (3 \times 16) \\ &= 63.5 + 12 + 48 \\ &= 123.5 \end{aligned}$$

$$\begin{aligned} \text{(h) Relative Molecular Mass Na}_2\text{CO}_3 &= (2 \times 23) + 12 + (3 \times 16) \\ &= 46 + 12 + 48 \\ &= 106 \end{aligned}$$

$$\begin{aligned} \text{(i) Relative Molecular Mass NaOH} &= 23 + 16 + 1 \\ &= 40 \end{aligned}$$

$$\begin{aligned} \text{(j) Relative Molecular Mass NO}_3^- &= 14 + (3 \times 16) \\ &= 14 + 48 \\ &= 62 \end{aligned}$$

$$\begin{aligned} \text{(k) Relative Molecular Mass Na}_2\text{CO}_3 \cdot 10 \text{ H}_2\text{O} &= (2 \times 23) + 12 + (3 \times 16) + (10 \times 18) \\ &= 46 + 12 + 48 + 180 \\ &= 286 \end{aligned}$$

$$\begin{aligned} \text{(l) Relative Molecular Mass Ca}_3\text{(PO}_4\text{)}_2 &= (3 \times 40) + (2 \times 31) + (8 \times 16) \\ &= 120 + 62 + 128 \\ &= 310 \end{aligned}$$

$$\begin{aligned} \text{(m) Relative Molecular Mass FeSO}_4 \cdot 7\text{H}_2\text{O} &= 56 + 32 + (4 \times 16) + (7 \times 18) \\ &= 56 + 32 + 64 + 126 \\ &= 278 \end{aligned}$$

$$\begin{aligned} \text{(n) Relative Molecular Mass C}_{12}\text{H}_{22}\text{O}_{11} &= (12 \times 12) + (22 \times 1) + (11 \times 16) \\ &= 144 + 22 + 176 \\ &= 342 \end{aligned}$$

**9.4**

$$\text{(a) Number of moles of Na} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{69}{23} = 3$$

$$\text{(b) Number of moles of Zn} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{162.5}{65} = 2.5$$

$$\text{(c) Number of moles of Cr} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{6.5}{52} = 0.125$$

$$(d) \quad \text{Number of moles of Cu} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{254}{63.5} = 4$$

$$(e) \quad \text{Number of moles of Pb} = \frac{\text{Mass}}{\text{Relative Atomic Mass}} = \frac{31.05}{207} = 0.15$$

### 9.5

$$(a) \quad \text{Relative Molecular Mass O}_2 = 2 \times 16 = 32$$

$$\text{Number of moles of O}_2 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{192}{32} = 6$$

$$(b) \quad \text{Relative Molecular Mass Br}_2 = 2 \times 80 = 160$$

$$\text{Number of moles of Br}_2 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{4}{160} = 0.025$$

$$(c) \quad \text{Relative Molecular Mass N}_2 = 2 \times 14 = 28$$

$$\text{Number of moles of N}_2 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{140}{28} = 5$$

$$(d) \quad \text{Relative Molecular Mass CO} = 12 + 16 = 28$$

$$\text{Number of moles of CO} = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{56}{28} = 2$$

$$(e) \quad \text{Relative Molecular Mass C}_2\text{H}_4 = (2 \times 12) + (4 \times 1) = 24 + 4 = 28$$

$$\text{Number of moles of C}_2\text{H}_4 = \frac{\text{Mass}}{\text{Relative Molecular Mass}} = \frac{0.7}{28} = 0.025$$

(f) Relative Molecular Mass  $\text{SO}_4^{2-} = 32 + (4 \times 16) = 32 + 64 = 96$

$$\text{Number of moles of } \text{SO}_4^{2-} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{9.6}{96} = 0.1$$

**9.6**

(a) 1 mole of C contains  $6 \times 10^{23}$  atoms

$$0.54 \text{ mole of C contains } 0.54 \times 6 \times 10^{23} \text{ atoms} \\ = 3.24 \times 10^{23} \text{ atoms}$$

(b) 1 mole of Sn contains  $6 \times 10^{23}$  atoms

$$1.24 \text{ moles of Sn contain } 1.24 \times 6 \times 10^{23} \text{ atoms} \\ = 7.44 \times 10^{23} \text{ atoms}$$

(c) 1 mole of Zn contains  $6 \times 10^{23}$  atoms

$$6.2 \text{ moles of Zn contain } 6.2 \times 6 \times 10^{23} \text{ atoms} \\ = 3.72 \times 10^{24} \text{ atoms}$$

(d) 1 mole of Fe contains  $6 \times 10^{23}$  atoms

$$200 \text{ moles of Fe contain } 200 \times 6 \times 10^{23} \text{ atoms} \\ = 1.2 \times 10^{26} \text{ atoms}$$

(e) 1 mole of Ag contains  $6 \times 10^{23}$  atoms

$$5 \times 10^{-5} \text{ mole of Ag contains } 5 \times 10^{-5} \times 6 \times 10^{23} \text{ atoms} \\ = 3 \times 10^{19} \text{ atoms}$$

**9.7**

(a) 1 mole of Al contains  $6 \times 10^{23}$  atoms

i.e. 27 g of Al contain  $6 \times 10^{23}$  atoms

$$1 \text{ g of Al contains } \frac{6 \times 10^{23}}{27} \text{ atoms}$$

$$54 \text{ g of Al contain } \frac{54 \times 6 \times 10^{23}}{27} \text{ atoms}$$

$$= 1.2 \times 10^{24} \text{ atoms}$$

- (b)** 1 mole of Ag contains  $6 \times 10^{23}$  atoms  
 i.e. 108 g of Ag contain  $6 \times 10^{23}$  atoms

$$1 \text{ g of Ag contains } \frac{6 \times 10^{23}}{108} \text{ atoms}$$

$$168 \text{ g of Ag contain } \frac{168 \times 6 \times 10^{23}}{108} \text{ atoms}$$

$$= 9.33 \times 10^{23} \text{ atoms}$$

- (c)** 1 mole of Mg contains  $6 \times 10^{23}$  atoms  
 i.e. 24 g of Mg contain  $6 \times 10^{23}$  atoms

$$1 \text{ g of Mg contains } \frac{6 \times 10^{23}}{24} \text{ atoms}$$

$$96 \text{ g of Mg contain } \frac{96 \times 6 \times 10^{23}}{24} \text{ atoms}$$

$$= 2.4 \times 10^{24} \text{ atoms}$$

- (d)** 1 mole of Fe contains  $6 \times 10^{23}$  atoms  
 i.e. 56 g of Fe contain  $6 \times 10^{23}$  atoms

$$1 \text{ g of Fe contains } \frac{6 \times 10^{23}}{56} \text{ atoms}$$

$$3.36 \text{ g of Fe contain } \frac{3.36 \times 6 \times 10^{23}}{56} \text{ atoms}$$

$$= 3.6 \times 10^{22} \text{ atoms}$$



- (e) 1 mole of C contains  $6 \times 10^{23}$  atoms  
 i.e. 12 g of C contain  $6 \times 10^{23}$  atoms

$$1 \text{ g of C contains } \frac{6 \times 10^{23}}{12} \text{ atoms}$$

$$\begin{aligned} 0.12 \text{ g of C contains } & \frac{0.12 \times 6 \times 10^{23}}{12} \text{ atoms} \\ & = 6 \times 10^{21} \text{ atoms} \end{aligned}$$

**9.8**

- (a)  $6 \times 10^{23}$  atoms of C = 1 mole

$$1 \text{ atom of C} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$\begin{aligned} 5 \times 10^{24} \text{ atoms of C} &= \frac{5 \times 10^{24}}{6 \times 10^{23}} \text{ mole} \\ &= 8.33 \text{ moles} \end{aligned}$$

- (b)  $6 \times 10^{23}$  atoms of Zn = 1 mole

$$1 \text{ atom of Zn} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$\begin{aligned} 8 \times 10^{26} \text{ atoms of Zn} &= \frac{8 \times 10^{26}}{6 \times 10^{23}} \text{ mole} \\ &= 1.33 \times 10^3 \text{ moles} \end{aligned}$$

- (c)  $6 \times 10^{23}$  atoms of Au = 1 mole

$$1 \text{ atom of Au} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$2.6 \times 10^{12} \text{ atoms of Au} = \frac{2.6 \times 10^{12}}{6 \times 10^{23}} \text{ mole}$$
$$= 4.33 \times 10^{-12} \text{ mole}$$

(d)  $6 \times 10^{23}$  atoms of Ag = 1 mole

$$1 \text{ atom of Ag} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$9.8 \times 10^{27} \text{ atoms of Ag} = \frac{9.8 \times 10^{27}}{6 \times 10^{23}} \text{ mole}$$
$$= 1.63 \times 10^4 \text{ moles}$$

(e)  $6 \times 10^{23}$  atoms of Mg = 1 mole

$$1 \text{ atom of Mg} = \frac{1}{6 \times 10^{23}} \text{ mole}$$

$$1.3 \times 10^6 \text{ atoms of Mg} = \frac{1.3 \times 10^6}{6 \times 10^{23}} \text{ mole}$$
$$= 2.17 \times 10^{-18} \text{ mole}$$

## Chapter 10 - Properties of Gases

### 10.1

Given

$$V_1 = 75 \text{ cm}^3$$

$$p_1 = 900 \text{ kPa}$$

$$T_1 = 20 \text{ }^\circ\text{C} + 273 = 293 \text{ K}$$

s.t.p.

$$V_2 = ?$$

$$p_2 = 100 \text{ kPa}$$

$$T_2 = 273 \text{ K}$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$\frac{900 \times 75}{293} = \frac{100 \times V_2}{273}$$

$$\Rightarrow V_2 = \frac{900 \times 75 \times 273}{293 \times 100}$$

$$= 628.92 \text{ cm}^3$$

### 10.2

Old

$$V_1 = 100 \text{ cm}^3$$

$$p_1 = 1 \times 10^5 \text{ Pa}$$

$$T_1 = T_2$$

New

$$V_2 = 55 \text{ cm}^3$$

$$p_2 = ?$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$1 \times 10^5 \times 100 = p_2 \times 55$$

$$\Rightarrow p_2 = \frac{1 \times 10^5 \times 100}{55}$$

$$= 181818.18 \text{ Pa}$$

$$\approx 1.8 \times 10^5 \text{ Pa}$$

### 10.3

$$\begin{array}{l} \text{Old} \\ V_1 = 5 \text{ L} \\ p_1 = 9.2 \times 10^4 \text{ Nm}^{-2} \\ T_1 = T_2 \end{array}$$

$$\begin{array}{l} \text{New} \\ V_2 = ? \\ p_2 = 1.01 \times 10^5 \text{ Nm}^{-2} \end{array}$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$9.2 \times 10^4 \times 5 = 1.01 \times 10^5 \times V_2$$

$$\Rightarrow V_2 = \frac{9.2 \times 10^4 \times 5}{1.01 \times 10^5}$$

$$= 4.55 \text{ L}$$

### 10.4

$$\begin{array}{l} \text{Old} \\ V_1 = 2500 \text{ L} \\ p_1 = 500 \text{ kPa} \\ T_1 = 100 \text{ }^\circ\text{C} + 273 = 373 \text{ K} \end{array}$$

$$\begin{array}{l} \text{New} \\ V_2 = ? \\ p_2 = 100 \text{ kPa} \\ T_2 = 20 \text{ }^\circ\text{C} + 273 = 293 \text{ K} \end{array}$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$\frac{500 \times 2500}{373} = \frac{100 \times V_2}{293}$$

$$\Rightarrow V_2 = \frac{500 \times 2500 \times 293}{373 \times 100}$$

$$= 9819.03 \text{ L}$$

**10.5**

	Nitrogen	+	Hydrogen	$\xrightarrow{\quad}$	Ammonia
	$\text{N}_2$		$\text{H}_2$	$\xrightarrow{\quad}$	$\text{NH}_3$
	$50 \text{ cm}^3$		$150 \text{ cm}^3$		$100 \text{ cm}^3$
<u>Ratio</u>	<b>1</b>	<b>:</b>	<b>3</b>	<b>:</b>	<b>2</b>

The volume of the reacting gases and the volume of the gaseous product are in simple whole number ratios as expected from Gay-Lussac's Law of Combining Volumes.

**10.6**

- (a) Rel molecular mass  $\text{NH}_3 = 14 + (3 \times 1) = 14 + 3 = 17$   
 i.e. 1 mole of  $\text{NH}_3 = 17 \text{ g}$   
 17 g of  $\text{NH}_3$  occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{17}{22.4} = 0.76 \text{ g/L}$$

- (b) Rel molecular mass  $\text{N}_2 = 2 \times 14 = 28$   
 i.e. 1 mole of  $\text{N}_2 = 28 \text{ g}$   
 28 g of  $\text{N}_2$  occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{28}{22.4} = 1.25 \text{ g/L}$$

- (c) Rel molecular mass  $\text{Cl}_2 = 2 \times 35.5 = 71$   
 i.e. 1 mole of  $\text{Cl}_2 = 71 \text{ g}$   
 71 g of  $\text{Cl}_2$  occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{71}{22.4} = 3.17 \text{ g/L}$$

- (d) Rel molecular mass  $\text{CH}_4 = 12 + (4 \times 1) = 12 + 4 = 16$   
 i.e. 1 mole of  $\text{CH}_4 = 16\text{g}$   
 16 g of  $\text{CH}_4$  occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{16}{22.4} = 0.71 \text{ g/L}$$

- (e) Rel molecular mass  $\text{O}_2 = 2 \times 16 = 32$   
 i.e. 1 mole of  $\text{O}_2 = 32 \text{g}$   
 32 g of  $\text{O}_2$  occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{32}{22.4} = 1.43 \text{ g/L}$$

- (f) Rel molecular mass  $\text{O}_3 = 3 \times 16 = 48$   
 i.e. 1 mole of  $\text{O}_3 = 48 \text{g}$   
 48 g of  $\text{O}_3$  occupy 22.4 L at s.t.p.

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{48}{22.4} = 2.14 \text{ g/L}$$

## 10.7

200  $\text{cm}^3$  have a mass of 1 g

1  $\text{cm}^3$  has a mass of  $\frac{1}{200}$  g

22,400  $\text{cm}^3$  have a mass of  $\frac{22,400}{200}$  g

= 112 g

i.e. 22.4 L of the gas have a mass of 112g  
 $\Rightarrow$  Relative molecular mass of gas = 112

**10.8**

<b>(d)</b>	<u>Laboratory</u>	<u>s.t.p.</u>
	$V_1 = 332 \text{ cm}^3$	$V_2 = ?$
	$p_1 = 1.2 \times 10^5 \text{ Pa}$	$p_2 = 1 \times 10^5 \text{ Pa}$
	$T_1 = 100 \text{ }^\circ\text{C} + 273 = 373 \text{ K}$	$T_2 = 273 \text{ K}$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$\frac{1.2 \times 10^5 \times 332}{373} = \frac{1 \times 10^5 \times V_2}{273}$$

$$\Rightarrow V_2 = \frac{1.2 \times 10^5 \times 332 \times 273}{373 \times 1 \times 10^5}$$

$$= 291.59 \text{ cm}^3$$

Mass of condensed liquid =  $109.72 - 108.41 = 1.31 \text{ g}$

At s.t.p.  $291.59 \text{ cm}^3$  of the vapour have a mass of  $1.31 \text{ g}$

$$1 \text{ cm}^3 \text{ of the vapour has a mass of } \frac{1.31}{291.59} \text{ g}$$

$$\Rightarrow 22,400 \text{ cm}^3 \text{ of the vapour have a mass of } \frac{22,400 \times 1.31}{291.59}$$

$$= 100.63 \text{ g}$$

i.e. Relative molecular mass of liquid =  $100.63$

**10.10** Relative molecular mass  $O_2 = 2 \times 16 = 32$ 

This problem can be solved using either:

(a) Ideal Gas Equation  $pV = nRT$

$$P = 20 \text{ kPa} = 20,000 \text{ Pa}$$

$$V = ?$$

$$n = \text{number of moles} = \frac{\text{Mass in grams}}{\text{Rel molecular mass}} = \frac{20}{32} = 0.625$$

$$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$T = 25 \text{ }^\circ\text{C} = 25 + 273 = 298 \text{ K}$$

$$pV = nRT$$

$$V = \frac{nRT}{p} = \frac{0.625 \times 8.31 \times 298}{20,000} = 0.0774 \text{ m}^3 = 0.0774 \times 1000 \text{ L} = 77.4 \text{ L}$$

**OR**

(b) Combined Gas Law  $\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$

Given

$$V_1 = ? \text{ cm}^3$$

$$p_1 = 20 \text{ kPa}$$

$$T_1 = 25 \text{ }^\circ\text{C} + 273 = 298 \text{ K}$$

s.t.p.

$$V_2 = 22.4 \text{ L}$$

$$p_2 = 101.3 \text{ kPa}$$

$$T_2 = 273 \text{ K}$$

$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2}$$

$$\frac{20 \times V_1}{298} = \frac{101.3 \times 22.4}{273}$$

$$\Rightarrow V_1 = \frac{101.3 \times 22.4 \times 298}{273 \times 20}$$



$$= 123.85 \text{ L}$$

1 mole of  $\text{O}_2$  occupies 123.85 L under the above conditions  
 i.e. 32 g of  $\text{O}_2$  occupies 123.85 L

$$1 \text{ g of } \text{O}_2 \text{ occupies } \frac{123.85}{32} \text{ L}$$

$$20 \text{ g of } \text{O}_2 \text{ occupies } \frac{123.85 \times 20}{32} \text{ L}$$

$$= 77.4 \text{ L}$$

### 10.11

$$p = 101.325 \text{ kPa} = 101,325 \text{ Pa}$$

$$V = 46 \text{ cm}^3 = 46 \times 10^{-6} \text{ m}^3$$

$$n = ?$$

$$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$T = 100 \text{ }^\circ\text{C} + 273 = 373 \text{ K}$$

$$pV = nRT$$

$$n = \frac{pV}{RT}$$

$$= \frac{101,325 \times 46 \times 10^{-6}}{8.31 \times 373}$$

$$= 1.504 \times 10^{-3} \text{ moles}$$

$$\text{i.e. } 1.504 \times 10^{-3} \text{ moles} = 0.16 \text{ g}$$

$$1 \text{ mole of liquid} = \frac{0.16}{1.504 \times 10^{-3}}$$

$$= 106.38$$

i.e. Relative molecular mass of liquid  $\approx 106$

### 10.12

$$p = 100.5 \text{ kPa} = 100,500 \text{ Pa}$$

$$V = 127 \text{ cm}^3 = 127 \times 10^{-6} \text{ m}^3$$

$$n = ?$$

$$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$$

$$T = 98 \text{ }^\circ\text{C} + 273 = 371 \text{ K}$$

$$pV = nRT$$

$$n = \frac{pV}{RT}$$

$$= \frac{100,500 \times 127 \times 10^{-6}}{8.31 \times 371}$$

$$= 4.14 \times 10^{-3} \text{ mole}$$

$$\text{i.e. } 4.14 \times 10^{-3} \text{ mole} = 0.495 \text{ g}$$

$$1 \text{ mole of liquid} = \frac{0.495}{4.14 \times 10^{-3}}$$

$$= 119.57$$

$$\text{i.e. Relative molecular mass of liquid} \approx 120$$

## Chapter 11 - Stoichiometry

### 11.1

(a) Relative molecular mass  $\text{MgO} = 24 + 16 = 40$

$$\% \text{ Mg} = \frac{24}{40} \times 100 = 60\%$$

$$\% \text{ O} = \frac{16}{40} \times 100 = 40\%$$

(b) Relative molecular mass  $\text{Al}_2\text{O}_3 = (2 \times 27) + (3 \times 16) = 54 + 48 = 102$

$$\% \text{ Al} = \frac{54}{102} \times 100 = 52.94\%$$

$$\% \text{ O} = \frac{48}{102} \times 100 = 47.06\%$$

(c) Relative molecular mass  $\text{MgSO}_4 = 24 + 32 + (4 \times 16) = 24 + 32 + 64 = 120$

$$\% \text{ Mg} = \frac{24}{120} \times 100 = 20\%$$

$$\% \text{ S} = \frac{32}{120} \times 100 = 26.67\%$$

$$\% \text{ O} = \frac{64}{120} \times 100 = 53.33\%$$

**(d)** Relative molecular mass  $\text{CaCO}_3 = 40 + 12 + (3 \times 16) = 40 + 12 + 48 = 100$

$$\% \text{ Ca} = \frac{40}{100} \times 100 = 40\%$$

$$\% \text{ C} = \frac{12}{100} \times 100 = 12\%$$

$$\% \text{ O} = \frac{48}{100} \times 100 = 48\%$$

**(e)** Relative molecular mass  $\text{NaCl} = 23 + 35.5 = 58.5$

$$\% \text{ Na} = \frac{23}{58.5} \times 100 = 39.32\%$$

$$\% \text{ Cl} = \frac{35.5}{58.5} \times 100 = 60.68\%$$

**(f)** Relative molecular mass  $(\text{NH}_4)_2\text{SO}_4 = (2 \times 14) + (8 \times 1) + 32 + (4 \times 16)$   
 $= 28 + 8 + 32 + 64$   
 $= 132$

$$\% \text{ N} = \frac{28}{132} \times 100 = 21.21\%$$

$$\% \text{ H} = \frac{8}{132} \times 100 = 6.06\%$$

$$\% \text{ S} = \frac{32}{132} \times 100 = 24.24\%$$

$$\% \text{ O} = \frac{64}{132} \times 100 = 48.48\%$$

$$\begin{aligned} \text{(g) Relative molecular mass } (\text{COOH})_2 &= (2 \times 12) + (4 \times 16) + (2 \times 1) \\ &= 24 + 64 + 2 \\ &= 90 \end{aligned}$$

$$\% \text{ C} = \frac{24}{90} \times 100 = 26.67\%$$

$$\% \text{ H} = \frac{2}{90} \times 100 = 2.22\%$$

$$\% \text{ O} = \frac{64}{90} \times 100 = 71.11\%$$

$$\begin{aligned} \text{(h) Relative molecular mass } \text{CH}_3\text{COOH} &= 12 + (3 \times 1) + 12 + (2 \times 16) + 1 \\ &= 12 + 3 + 12 + 32 + 1 \\ &= 60 \end{aligned}$$

$$\% \text{ C} = \frac{24}{60} \times 100 = 40\%$$

$$\% \text{ H} = \frac{4}{60} \times 100 = 6.67\%$$

$$\% \text{ O} = \frac{32}{60} \times 100 = 53.33\%$$

$$\begin{aligned} \text{(i) Relative molecular mass } \text{Pb}(\text{NO}_3)_2 &= 207 + (2 \times 14) + (6 \times 16) \\ &= 207 + 28 + 96 \\ &= 331 \end{aligned}$$

$$\% \text{ Pb} = \frac{207}{331} \times 100 = 62.54\%$$

$$\% \text{ N} = \frac{28}{331} \times 100 = 8.46\%$$

$$\% \text{ O} = \frac{96}{331} \times 100 = 29\%$$

$$\begin{aligned} \text{(j) Relative molecular mass } \text{KHCO}_3 &= 39 + 1 + 12 + (3 \times 16) \\ &= 39 + 1 + 12 + 48 \\ &= 100 \end{aligned}$$

$$\% \text{ K} = \frac{39}{100} \times 100 = 39\%$$

$$\% \text{ C} = \frac{12}{100} \times 100 = 12\%$$

$$\% \text{ H} = \frac{1}{100} \times 100 = 1\%$$

$$\% \text{ O} = \frac{48}{100} \times 100 = 48\%$$

## 11.2

$$\begin{aligned} \text{Relative molecular mass } \text{NH}_4\text{NO}_3 &= 14 + (1 \times 4) + 14 + (16 \times 3) \\ &= 14 + 4 + 14 + 48 \\ &= 80 \end{aligned}$$

$$\% \text{ N} = \frac{28}{80} \times 100 = 35 \%$$

$$\begin{aligned} \text{Relative molecular mass } (\text{NH}_4)_2\text{SO}_4 &= (14 \times 2) + (1 \times 8) + 32 + (16 \times 4) \\ &= 28 + 8 + 32 + 64 \\ &= 132 \end{aligned}$$

$$\% \text{ N} = \frac{28}{132} \times 100 = 21.21 \%$$

$$\begin{aligned} \text{Relative molecular mass } (\text{NH}_2)_2\text{CO} &= (14 \times 2) + (1 \times 4) + 12 + 16 \\ &= 28 + 4 + 12 + 16 \\ &= 60 \end{aligned}$$

$$\% \text{ N} = \frac{28}{60} \times 100 = 46.67 \%$$

Urea  $(\text{NH}_2)_2\text{CO}$  contains the highest % of N.

**11.3**

$C_6H_6$  :- Empirical formula = CH

$C_2H_4O_2$  :- Empirical formula =  $CH_2O$

$C_3H_6O_3$  :- Empirical formula =  $CH_2O$

**11.4**

Molecular Formula = empirical formula  $\times$  n

$$60 = (N_2H_4CO) \times n$$

$$60 = [(14 \times 2) + (1 \times 4) + 12 + 16] n$$

$$60 = (28 + 4 + 12 + 16) n$$

$$60 = 60n$$

$$n = 1$$

$\Rightarrow$  Molecular Formula =  $(N_2H_4CO) \times 1$   
 =  $N_2H_4CO$

**11.5****(a)**

Element	Percentage	$\frac{\text{Percentage}}{\text{Rel. At. Mass}}$	Simplest ratio (divide by 3.31)
Nitrogen	47	$\frac{47}{14} = 3.36$	$\frac{3.36}{3.31} = 1$
Oxygen	53	$\frac{53}{16} = 3.31$	$\frac{3.31}{3.31} = 1$

*i.e.* Empirical formula = NO

**(b)**

Element	Percentage	$\frac{\text{Percentage}}{\text{Rel. At. Mass}}$	Simplest ratio (divide by 2.18)
Nitrogen	30.5	$\frac{30.5}{14} = 2.18$	$\frac{2.18}{2.18} = 1$
Oxygen	69.5	$\frac{69.5}{16} = 4.34$	$\frac{4.34}{2.18} = 2$

*i.e.* Empirical formula =  $NO_2$

(c)

Element	<u>Percentage</u>	<u>Percentage</u> Rel. At. Mass	Simplest ratio (divide by 6.25)
Carbon	75	$\frac{75}{12} = 6.25$	$\frac{6.25}{6.25} = 1$
Hydrogen	25	$\frac{25}{1} = 25$	$\frac{25}{6.25} = 4$

*i.e.* Empirical formula = CH<sub>4</sub>

(d)

Element	<u>Percentage</u>	<u>Percentage</u> Rel. At. Mass	Simplest ratio (divide by 7.14)
Carbon	85.7	$\frac{85.7}{12} = 7.14$	$\frac{7.14}{7.14} = 1$
Hydrogen	14.3	$\frac{14.3}{1} = 14.3$	$\frac{14.3}{7.14} = 2$

*i.e.* Empirical formula = CH<sub>2</sub>

(e)

Element	<u>Percentage</u>	<u>Percentage</u> Rel. At. Mass	Simplest ratio (divide by 0.62)
Iron	34.5	$\frac{34.5}{56} = 0.62$	$\frac{0.62}{0.62} = 1$
Chlorine	65.5	$\frac{65.5}{35.5} = 1.85$	$\frac{1.85}{0.62} = 3$

*i.e.* Empirical formula = FeCl<sub>3</sub>

(f)

Element	<u>Percentage</u>	<u>Percentage</u> Rel. At. Mass	Simplest ratio (divide by 7.7)
Carbon	92.3	$\frac{92.3}{12} = 7.69$	$\frac{7.69}{7.7} = 1$
Hydrogen	7.7	$\frac{7.7}{1} = 7.7$	$\frac{7.7}{7.7} = 1$

*i.e.* Empirical formula = CH



(g)

Element	Percentage	$\frac{\text{Percentage}}{\text{Rel. At. Mass}}$	Simplest ratio (divide by 1.25)
Sulphur	40	$\frac{40}{32} = 1.25$	$\frac{1.25}{1.25} = 1$
Oxygen	60	$\frac{60}{16} = 3.75$	$\frac{3.75}{1.25} = 3$

*i.e.* Empirical formula = SO<sub>3</sub>

(h)

Element	Percentage	$\frac{\text{Percentage}}{\text{Rel. At. Mass}}$	Simplest ratio (divide by 1.56)
Sulphur	50	$\frac{50}{32} = 1.56$	$\frac{1.56}{1.56} = 1$
Oxygen	50	$\frac{50}{16} = 3.13$	$\frac{3.13}{1.56} = 2$

*i.e.* Empirical formula = SO<sub>2</sub>

(i)

Element	Percentage	$\frac{\text{Percentage}}{\text{Rel. At. Mass}}$	Simplest ratio (divide by 0.52)
Potassium	40.2	$\frac{40.2}{39} = 1.03$	$\frac{1.03}{0.52} = 2$
Chromium	26.9	$\frac{26.9}{52} = 0.52$	$\frac{0.52}{0.52} = 1$
Oxygen	32.9	$\frac{32.9}{16} = 2.06$	$\frac{2.06}{0.52} = 4$

*i.e.* Empirical formula = K<sub>2</sub>CrO<sub>4</sub>

(j)

Element	<u>Percentage</u>	<u>Percentage</u> ————— Rel. At. Mass	Simplest ratio (divide by 0.68)	Multiply by 2 to get whole numbers.
Potassium	26.6	26.6 ———— = 0.68 39	0.68 ———— = 1 0.68	$1 \times 2 = 2$
Chromium	35.4	35.4 ———— = 0.68 52	0.68 ———— = 1 0.68	$1 \times 2 = 2$
Oxygen	38	38 ———— = 2.38 16	2.38 ———— = 3.5 0.68	$3.5 \times 2 = 7$

*i.e.* Empirical formula =  $K_2Cr_2O_7$

(k)

Element	<u>Percentage</u>	<u>Percentage</u> ————— Rel. At. Mass	Simplest ratio (divide by 0.54)
Copper	34.6	34.6 ———— = 0.54 63.5	0.54 ———— = 1 0.54
Iron	30.5	30.5 ———— = 0.54 56	0.54 ———— = 1 0.54
Sulphur	34.9	34.9 ———— = 1.09 32	1.09 ———— = 2 0.54

*i.e.* Empirical formula =  $CuFeS_2$

### 11.6

Element	<u>Percentage</u>	<u>Percentage</u> ————— Rel. At. Mass	Simplest ratio (divide by 0.35)
Carbon	4.2	4.2 ———— = 0.35 12	0.35 ———— = 1 0.35
Oxygen	16.8	16.8 ———— = 1.05 16	1.05 ———— = 3 0.35
Sodium	16.1	16.1 ———— = 0.7 23	0.7 ———— = 2 0.35
Water	62.9	62.9 ———— = 3.49 18	3.49 ———— = 10 0.35

*i.e.* Empirical formula =  $Na_2CO_3 \cdot 10H_2O$

**11.7**

calcium + oxygen  $\longrightarrow$  calcium oxide  
 2 g 2.8 g

mass of calcium = 2 g

mass of calcium oxide = 2.8 g

$\Rightarrow$  mass of oxygen in calcium oxide =  $2.8 - 2 = 0.8$  g

number of moles of calcium in calcium oxide =  $\frac{\text{mass}}{\text{Rel. atomic mass}}$

$$= \frac{2}{40} = 0.05$$

number of moles of oxygen in calcium oxide =  $\frac{\text{mass}}{\text{Rel. atomic mass}}$

$$= \frac{0.8}{16} = 0.05$$

Ratio of Ca : O =  $0.05 : 0.05 = 1 : 1$

$\Rightarrow$  Empirical Formula = CaO

**11.8**

aluminium + oxygen  $\longrightarrow$  aluminium oxide  
 2.7 g 5.1 g

mass of aluminium = 2.7 g

mass of aluminium oxide = 5.1 g

mass of oxygen in aluminium oxide =  $5.1 - 2.7 = 2.4$  g

number of moles of aluminium in aluminium oxide =  $\frac{\text{mass}}{\text{Rel. atomic mass}}$

$$= \frac{2.7}{27} = 0.1$$

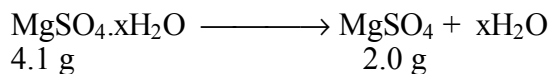
number of moles of oxygen in aluminium oxide =  $\frac{\text{mass}}{\text{Rel. atomic mass}}$

$$= \frac{2.4}{16} = 0.15$$

Ratio of Al : O =  $0.1 : 0.15 = 2 : 3$

$\Rightarrow$  Empirical Formula =  $\text{Al}_2\text{O}_3$

### 11.9



4.1 g

2.0 g

mass of  $\text{MgSO}_4 = 2 \text{ g}$

mass of  $\text{MgSO}_4 \cdot x\text{H}_2\text{O} = 4.1 \text{ g}$

mass of  $\text{H}_2\text{O}$  in  $\text{MgSO}_4 \cdot x\text{H}_2\text{O} = 4.1 - 2 = 2.1 \text{ g}$

Rel. mol. mass  $\text{MgSO}_4 = 24 + 32 + (16 \times 4)$   
 $= 24 + 32 + 64 = 120$

Rel. mol. mass  $\text{H}_2\text{O} = (1 \times 2) + 16 = 18$

$$\begin{aligned} \text{number of moles of } \text{MgSO}_4 \text{ in } \text{MgSO}_4 \cdot x\text{H}_2\text{O} &= \frac{\text{mass}}{\text{Rel. mol. mass}} \\ &= \frac{2}{120} = 0.0167 \end{aligned}$$

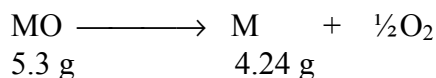
$$\begin{aligned} \text{number of moles of water } \text{MgSO}_4 \cdot x\text{H}_2\text{O} &= \frac{\text{mass}}{\text{Rel. mol. mass}} \\ &= \frac{2.1}{18} = 0.1167 \end{aligned}$$

Ratio of  $\text{MgSO}_4 : \text{H}_2\text{O} = 0.0167 : 0.1167 = 1 : 7$

$\Rightarrow \text{MgSO}_4 \cdot 7\text{H}_2\text{O}$  is the formula of the hydrated salt.

i.e. Degree of hydration = 7

### 11.10



5.3 g

4.24 g

mass of metal oxide = 5.3 g

mass of metal = 4.24 g

mass of oxygen =  $5.3 - 4.24 = 1.06 \text{ g}$

$$\begin{aligned} \text{number of moles of } \text{O}_2 &= \frac{\text{mass}}{\text{Rel. mol. mass}} \\ &= \frac{1.06}{16} = 0.0663 \end{aligned}$$

Since in the compound MO the ratio  $\text{M} : \text{O} = 1 : 1$

$\Rightarrow$  number of moles of metal = 0.0663

i.e. 0.0663 moles of M = 4.24 g

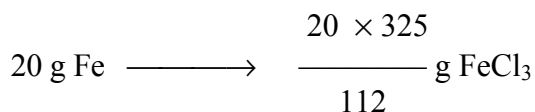
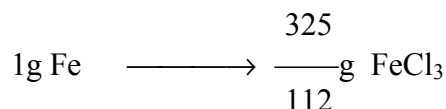
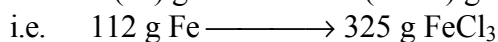
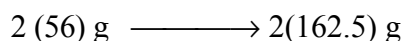
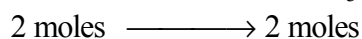
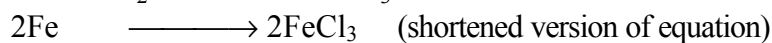
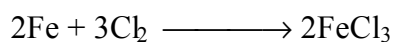
$$1 \text{ mole of M} = \frac{4.24}{0.0663}$$

$$= 63.95 \approx 64$$

i.e. Relative atomic mass of M = 64

**11.11**

$$\begin{aligned}\text{Rel. mol. mass FeCl}_3 &= 56 + (35.5 \times 3) \\ &= 56 + 106.5 = 162.5\end{aligned}$$

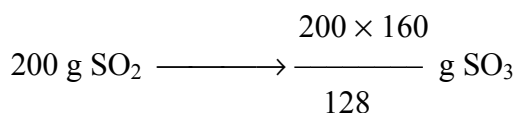
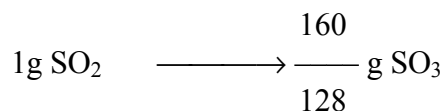
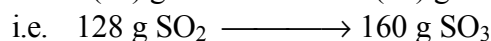
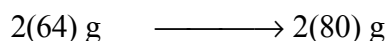
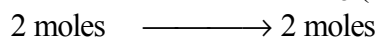
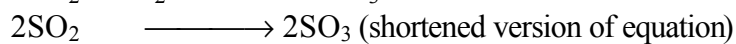
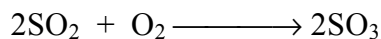


$$= 58.04 \text{ g FeCl}_3$$

**11.12**

$$\begin{aligned}\text{Rel. mol. mass SO}_2 &= 32 + (16 \times 2) \\ &= 32 + 32 = 64\end{aligned}$$

$$\begin{aligned}\text{Rel. mol. mass SO}_3 &= 32 + (16 \times 3) \\ &= 32 + 48 = 80\end{aligned}$$

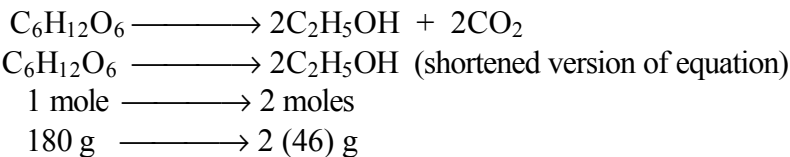


$$= 250 \text{ g SO}_3$$

### 11.13

$$\begin{aligned} \text{Rel. mol. mass C}_6\text{H}_{12}\text{O}_6 &= (12 \times 6) + (1 \times 12) + (16 \times 6) \\ &= 72 + 12 + 96 = 180 \end{aligned}$$

$$\begin{aligned} \text{Rel. mol. mass C}_2\text{H}_5\text{OH} &= (12 \times 2) + (1 \times 5) + 16 + 1 \\ &= 24 + 5 + 16 + 1 = 46 \end{aligned}$$



$$\text{i.e. } 180 \text{ g C}_6\text{H}_{12}\text{O}_6 \longrightarrow 92 \text{ g C}_2\text{H}_5\text{O}$$

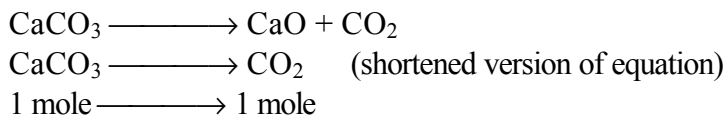
$$1 \text{ g C}_6\text{H}_{12}\text{O}_6 \longrightarrow \frac{92}{180} \text{ g C}_2\text{H}_5\text{OH}$$

$$25 \text{ g C}_6\text{H}_{12}\text{O}_6 \longrightarrow \frac{25 \times 92}{180} \text{ g C}_2\text{H}_5\text{OH}$$

$$= 12.78 \text{ g C}_2\text{H}_5\text{OH}$$

### 11.14

$$\begin{aligned} \text{Rel. mol. mass CaCO}_3 &= 40 + 12 + (16 \times 3) \\ &= 40 + 12 + 48 = 100 \end{aligned}$$



$$\text{i.e. } 100 \text{ g CaCO}_3 \longrightarrow 22.4 \text{ L of CO}_2 \text{ at s.t.p.}$$

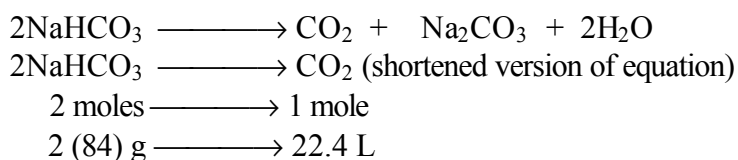
$$1 \text{ g CaCO}_3 \longrightarrow \frac{22.4}{100} \text{ L of CO}_2$$

$$2.5 \text{ g CaCO}_3 \longrightarrow \frac{2.5 \times 22.4}{100} \text{ L of CO}_2$$

$$= 0.56 \text{ L of CO}_2$$

**11.15**

$$\begin{aligned}\text{Relative mol. mass NaHCO}_3 &= 23 + 1 + 12 + (16 \times 3) \\ &= 23 + 1 + 12 + 48 = 84\end{aligned}$$



$$\begin{aligned}\text{i.e. } 168 \text{ g NaHCO}_3 &\longrightarrow 22.4 \text{ L of CO}_2 \text{ at s.t.p.} \\ 168 \text{ g NaHCO}_3 &\longrightarrow 22,400\text{cm}^3 \text{ CO}_2 \text{ at s.t.p.}\end{aligned}$$

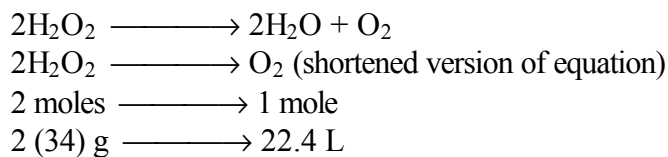
$$\frac{168}{22,400} \text{ g NaHCO}_3 \longrightarrow 1 \text{ cm}^3 \text{ CO}_2$$

$$\frac{800 \times 168}{22,400} \text{ g NaHCO}_3 \longrightarrow 800 \text{ cm}^3 \text{ CO}_2$$

$$= 6 \text{ g NaHCO}_3$$

**11.16**

$$\begin{aligned}\text{Relative mol. mass H}_2\text{O}_2 &= (1 \times 2) + (16 \times 2) \\ &= 2 + 32 = 34\end{aligned}$$



$$\text{i.e. } 68 \text{ g H}_2\text{O}_2 \longrightarrow 22.4 \text{ L of O}_2 \text{ at s.t.p.}$$

$$1 \text{ g H}_2\text{O}_2 \longrightarrow \frac{22.4}{68} \text{ L of O}_2$$

$$21 \text{ g H}_2\text{O}_2 \longrightarrow \frac{21 \times 22.4}{68} \text{ L of O}_2$$

$$= 6.92 \text{ L of O}_2$$

## Chapter 13 - Volumetric Analysis: Acid - Base

### 13.1

$$\% \text{ w/w salt} = \frac{148}{1300} \times 100 = 11.38\%$$

**OR**

1300 g of solution contains 148 g of salt

$$1 \text{ g contains } \frac{148}{1300} \text{ g of salt}$$

$$100 \text{ g contains } \frac{148}{1300} \times 100 = 11.38\%$$

$$\% \text{ w/w salt} = 11.38\%$$

### 13.2

$$\begin{aligned} \text{(a) } 0.75 \text{ g / L} &= 0.75 \times 1000 \text{ mg/L} \\ &= 750 \text{ mg/L} \\ &= 750 \text{ ppm} \end{aligned}$$

$$\begin{aligned} \text{(b) } 0.06 \text{ g / L} &= 0.06 \times 1000 \text{ mg/L} \\ &= 60 \text{ mg/L} \\ &= 60 \text{ ppm} \end{aligned}$$

$$\begin{aligned} \text{(c) } 0.017 \text{ g / } 100\text{cm}^3 &= 0.017 \times 10 \text{ g/L} \\ &= 0.17 \text{ g/L} \\ &= 0.17 \times 1000 \text{ mg/L} \\ &= 170 \text{ mg/L} \\ &= 170 \text{ ppm} \end{aligned}$$

$$\begin{aligned} \text{(d) } 0.0003 \text{ g / } 100\text{cm}^3 &= 0.0003 \times 10 \text{ g / L} \\ &= 0.003 \text{ g / L} \\ &= 0.003 \times 1000 \text{ mg/L} \\ &= 3 \text{ mg / L} \\ &= 3 \text{ ppm} \end{aligned}$$

### 13.3

$$\begin{aligned} \text{(a) Rel. mol mass NaOH} &= 23 + 16 + 1 = 40 \\ \Rightarrow 1 \text{ M NaOH} &= 40 \text{ g/L} \end{aligned}$$



**(b)** Rel. mol mass KOH = 39 + 16 + 1 = 56

$$1 \text{ M KOH} = 56 \text{ g / L}$$

$$\Rightarrow 2 \text{ M KOH} = (56 \times 2) \text{ g / L} \\ = 112 \text{ g/L}$$

**(c)** Rel. mol mass H<sub>2</sub>SO<sub>4</sub> = 2(1) + 32 + 4(16)  
= 2 + 32 + 64 = 98

$$1 \text{ M H}_2\text{SO}_4 = 98 \text{ g / L}$$

$$\Rightarrow 0.125 \text{ M H}_2\text{SO}_4 = (0.125 \times 98) \text{ g / L} \\ = 12.25 \text{ g/L}$$

**(d)** Rel. mol mass Na<sub>2</sub>CO<sub>3</sub> = 2(23) + 12 + 3(16)  
= 46 + 12 + 48 = 106

$$1 \text{ M Na}_2\text{CO}_3 = 106 \text{ g / L}$$

$$\Rightarrow 0.01 \text{ M Na}_2\text{CO}_3 = (0.01 \times 106) \text{ g / L} \\ = 1.06 \text{ g/L}$$

**(e)** Rel. mol mass HNO<sub>3</sub> = 1 + 14 + 3(16)  
= 1 + 14 + 48 = 63

$$1 \text{ M HNO}_3 = 63 \text{ g/L}$$

$$\Rightarrow 0.005 \text{ M HNO}_3 = (0.005 \times 63) \text{ g/L} \\ = 0.315 \text{ g/L}$$

### 13.4

**(a)** Rel. mol mass NaOH = 23 + 16 + 1 = 40

$$40 \text{ g NaOH in 1L of solution} \longrightarrow 1 \text{ M solution}$$

$$\Rightarrow 1 \text{ g NaOH in 1L of solution} \longrightarrow \frac{1}{40} \text{ M solution} \\ = 0.025 \text{ M}$$

**(b)** Rel. mol mass H<sub>2</sub>SO<sub>4</sub> = 2(1) + 32 + 4(16)  
= 2 + 32 + 64 = 98

$$98 \text{ g H}_2\text{SO}_4 \text{ in 1L of solution} \longrightarrow 1 \text{ M solution}$$

$$1 \text{ g H}_2\text{SO}_4 \text{ in 1L of solution} \longrightarrow \frac{1}{98} \text{ M solution}$$

$$24 \text{ g H}_2\text{SO}_4 \text{ in 1L of solution} \longrightarrow \frac{24}{98} \text{ M solution}$$

$$24 \text{ g H}_2\text{SO}_4 \text{ in } 500 \text{ cm}^3 \text{ of solution} \longrightarrow \frac{24 \times 2}{98} \text{ M solution} \\ = 0.49 \text{ M}$$

(c) Rel. mol mass HCl = 1 + 35.5 = 36.5

36.5 g HCl in 1L of solution → 1M solution

1 g HCl in 1L of solution →  $\frac{1}{36.5}$  M solution

22 g HCl in 1L of solution →  $\frac{22}{36.5}$  M solution

22g HCl in 200cm<sup>3</sup> of solution →  $\frac{22 \times 5}{36.5}$  M solution  
= 3.01 M

(d) Rel. mol mass NaOH = 23 + 16 + 1 = 40

40 g NaOH in 1L of solution → 1M solution

1 g NaOH in 1L of solution →  $\frac{1}{40}$  M solution

20 g NaOH in 1L of solution →  $\frac{20}{40}$  M solution

20g NaOH in 100cm<sup>3</sup> of solution →  $\frac{20 \times 10}{40}$  M solution  
= 5 M

(e) Rel. mol mass NaOH = 23 + 16 + 1 = 40

40 g NaOH in 1L of solution → 1M solution

1 g NaOH in 1L of solution →  $\frac{1}{40}$  M solution

4 g NaOH in 1L of solution →  $\frac{4}{40}$  M solution

4 g NaOH in 1 cm<sup>3</sup> of solution →  $\frac{4 \times 1000}{40}$  M solution

4 g NaOH in 750 cm<sup>3</sup> of solution →  $\frac{4 \times 1000}{40 \times 750}$  M solution  
= 0.13 M

**13.5**

$$\begin{aligned} \text{(a)} \quad \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{25 \times 0.01}{1000} \\ &= 2.5 \times 10^{-4} \text{ moles} \end{aligned}$$

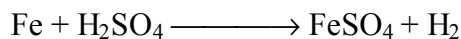
$$\begin{aligned} \text{(b)} \quad \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{18 \times 2.5}{1000} \\ &= 0.045 \text{ moles} \end{aligned}$$

$$\begin{aligned} \text{(c)} \quad \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{8.7 \times 0.5}{1000} \\ &= 4.35 \times 10^{-3} \text{ moles} \end{aligned}$$

$$\begin{aligned} \text{(d)} \quad \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{100 \times 0.005}{1000} \\ &= 5 \times 10^{-4} \text{ moles} \end{aligned}$$

$$\begin{aligned} \text{(e)} \quad \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{50 \times 0.09}{1000} \\ &= 4.5 \times 10^{-3} \text{ moles} \end{aligned}$$

**13.6**



$$\begin{aligned} \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{75 \times 0.5}{1000} \\ &= 0.0375 \text{ moles} \end{aligned}$$

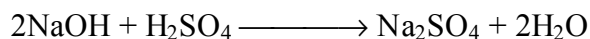
From the balanced equation, one mole of sulfuric acid reacts with one mole of iron.

$\Rightarrow$  0.0375 moles of Fe react

Rel. atomic mass Fe = 56

$$\begin{aligned} \text{mass of Fe reacting} &= \text{number of moles} \times \text{rel. atomic mass} \\ &= 0.0375 \times 56 \\ &= 2.1 \text{ g} \end{aligned}$$

**13.7**



$$\begin{aligned} \text{Number of moles of H}_2\text{SO}_4 &= \frac{\text{Volume} \times \text{Molarity}}{1000} \\ &= \frac{25 \times 2}{1000} \\ &= 0.05 \text{ moles} \end{aligned}$$

From the balanced equation, one mole of sulfuric acid reacts with 2 moles of sodium hydroxide.

$\Rightarrow$  (0.05  $\times$  2) moles = 0.1 moles of NaOH react with 0.05 moles H<sub>2</sub>SO<sub>4</sub>

Rel. mol mass NaOH = 23 + 16 + 1 = 40

$$\begin{aligned} \text{mass of NaOH reacting} &= \text{number of moles} \times \text{rel. mol mass} \\ &= 0.1 \times 40 \\ &= 4 \text{ g} \end{aligned}$$

**13.8**

Given:-

$$\text{Vol}_{\text{dil}} = 500 \text{ cm}^3$$

$$M_{\text{dil}} = 0.25 \text{ M}$$

$$\text{Vol}_{\text{conc}} = ?$$

$$M_{\text{conc}} = 10 \text{ M}$$

$$\frac{\text{Vol}_{\text{dil}} \times M_{\text{dil}}}{\cancel{1000}} = \frac{\text{Vol}_{\text{conc}} \times M_{\text{conc}}}{\cancel{1000}}$$

$$500 \times 0.25 = \text{Vol}_{\text{conc}} \times 10$$

$$\Rightarrow \text{Vol}_{\text{conc}} = \frac{500 \times 0.25}{10}$$

$$= 12.5 \text{ cm}^3$$

i.e. 12.5 cm<sup>3</sup> of 10 M acid would have to be diluted to 500 cm<sup>3</sup>.

**13.9**

Given:-

$$\text{Vol}_{\text{dil}} = 10,000 \text{ cm}^3$$

$$M_{\text{dil}} = 1 \text{ M}$$

$$\text{Vol}_{\text{conc}} = ?$$

$$M_{\text{conc}} = 18 \text{ M}$$

$$\frac{\text{Vol}_{\text{dil}} \times M_{\text{dil}}}{\cancel{1000}} = \frac{\text{Vol}_{\text{conc}} \times M_{\text{conc}}}{\cancel{1000}}$$

$$10,000 \times 1 = \text{Vol}_{\text{conc}} \times 18$$

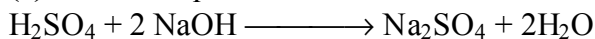
$$\Rightarrow \text{Vol}_{\text{conc}} = \frac{10,000 \times 1}{18}$$

$$= 555.56 \text{ cm}^3$$

i.e. 555.56 cm<sup>3</sup> of 18 M acid would have to be diluted to 10 L.

### 13.11

(a) Balanced equation:



Given:

$$V_a = 11.5 \text{ cm}^3$$

$$M_a = 0.5 \text{ M}$$

$$n_a = 1$$

$$V_b = 25 \text{ cm}^3$$

$$M_b = ?$$

$$n_b = 2$$

$$\begin{array}{ccc} & \text{H}_2\text{SO}_4 & \text{NaOH} \\ & \frac{V_a \times M_a}{n_a} & = \frac{V_b \times M_b}{n_b} \\ & \frac{11.5 \times 0.5}{1} & = \frac{25 \times M_b}{2} \\ \Rightarrow M_b & = & \frac{11.5 \times 0.5 \times 2}{25} \\ & & = 0.46 \text{ moles / L} \end{array}$$

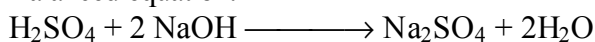
(b) Rel. mol mass NaOH = 23 + 16 + 1 = 40

$$\begin{aligned} \text{Concentration of NaOH in g/L} &= \text{number of moles/L} \times \text{rel. mol mass} \\ &= 0.46 \times 40 \\ &= 18.4 \text{ g / L} \end{aligned}$$

Answers (a) 0.46 moles/L  
(b) 18.4 g/L

### 13.12

Balanced equation:



Given:-

$$V_a = \frac{16.7 + 16.8}{2} = 16.75 \text{ cm}^3$$

$$M_a = 0.15 \text{ M}$$

$$n_a = 1$$

$$V_b = 25 \text{ cm}^3$$

$$M_b = ?$$

$$n_b = 2$$

$$\begin{array}{ccc} & \text{H}_2\text{SO}_4 & \text{NaOH} \\ & \frac{V_a \times M_a}{n_a} & = \frac{V_b \times M_b}{n_b} \\ & \frac{16.75 \times 0.15}{1} & = \frac{25 \times M_b}{2} \\ \Rightarrow M_b & = & \frac{16.75 \times 0.15 \times 2}{25} \\ & & = 0.201 \text{ moles / L} \\ & & = 0.201 \times 40 \text{ g/L} \\ & & = 8.04 \text{ g / L} \end{array}$$

(Rel. mol mass NaOH = 23 + 16 + 1 = 40)

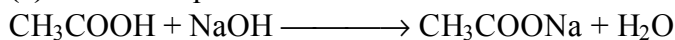
$$8.04 \text{ g NaOH} / \text{L} = (8.04 / 4) \text{ g NaOH} / 250 \text{ cm}^3$$

$$= 2.01 \text{ g NaOH} / 250 \text{ cm}^3$$

$$\% \text{ purity of sample} = \frac{2.01}{2.5} \times 100 = 80.4\%$$

### 13.13

(a) Balanced equation:



Given:-

$$V_a = 15.8 \text{ cm}^3$$

$$M_a = ?$$

$$n_a = 1$$

$$V_b = 25 \text{ cm}^3$$

$$M_b = 0.11 \text{ M}$$

$$n_b = 1$$

CH <sub>3</sub> COOH	=	NaOH
$\frac{V_a \times M_a}{n_a}$		$\frac{V_b \times M_b}{n_b}$
$\frac{15.8 \times M_a}{1}$	=	$\frac{25 \times 0.11}{1}$

$$\Rightarrow M_a = \frac{25 \times 0.11}{15.8}$$

$$= 0.174 \text{ moles / L}$$

$$\Rightarrow \text{Concentration of original solution} = 0.174 \times 5 \text{ (5 times more concentrated)}$$

$$= 0.87 \text{ moles/L} \dots\dots\dots\text{(a)}$$

$$= 0.87 \times 60$$

$$= 52.2 \text{ g/L} \dots\dots\dots\text{(b)}$$

$$M_r \text{ CH}_3\text{COOH} = 12 + 3(1) + 12 + 2(16) + 1 = 12 + 3 + 12 + 32 + 1 = 60$$

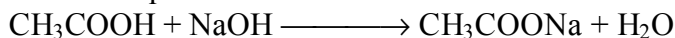
$$\text{Concentration of CH}_3\text{COOH in w/v} = 5.22 \text{ g/100 cm}^3 = 5.22\% \text{ w/v} \dots\dots\text{(c)}$$

- Answers:
- (a) 0.87 moles/L
  - (b) 52.2 g/L
  - (c) 5.22% w/v

**13.14**

(a)

Balanced equation:



Given:

$$V_a = 26.55 \text{ cm}^3$$

$$M_a = ?$$

$$n_a = 1$$

$$V_b = 25 \text{ cm}^3$$

$$M_b = 0.09 \text{ M}$$

$$n_b = 1$$

CH <sub>3</sub> COOH	=	NaOH
$\frac{V_a \times M_a}{n_a}$		$\frac{V_b \times M_b}{n_b}$
$\frac{26.55 \times M_a}{1}$	=	$\frac{25 \times 0.09}{1}$

$$\Rightarrow M_a = \frac{25 \times 0.09}{26.55}$$

$$= 0.0847 \text{ moles/L}$$

$$\Rightarrow \text{Concentration of original solution} = 0.0847 \times 10 \text{ (10 times more concentrated)}$$

$$= 0.847 \text{ moles / L .....(a)}$$

$$= 0.847 \times 60$$

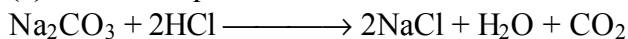
$$= 50.82 \text{ g/L .....(b)}$$

$$M_r \text{ CH}_3\text{COOH} = 12 + 3(1) + 12 + 2(16) + 1 = 12 + 3 + 12 + 32 + 1 = 60$$

$$\text{Concentration of CH}_3\text{COOH in w/v} = 5.08 \text{ g/100 cm}^3 = 5.08\% \text{ w/v .....(c)}$$

- Answers: (a) 0.847 moles/L  
 (b) 50.82 g/L  
 (c) 5.08% w/v



**13.15****(a)** Balanced equation:

Given:

$$V_a = 29.38 \text{ cm}^3$$

$$M_a = 0.17 \text{ M}$$

$$n_a = 2$$

$$V_b = 25 \text{ cm}^3$$

$$M_b = ?$$

$$n_b = 1$$

$$\begin{array}{ccc} \text{HCl} & & \text{Na}_2\text{CO}_3 \\ \frac{V_a \times M_a}{n_a} & = & \frac{V_b \times M_b}{n_b} \\ \frac{29.38 \times 0.17}{2} & = & \frac{25 \times M_b}{1} \\ \Rightarrow M_b & = & \frac{29.38 \times 0.17}{25 \times 2} \\ & = & 0.0999 \text{ moles/L} \end{array}$$

$$0.0999 \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O/L} = (0.0999 / 4) \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O} / 250 \text{ cm}^3 \\ = 0.025 \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O} / 250 \text{ cm}^3$$

$$1 \text{ mole Na}_2\text{CO}_3 = 2(23) + 12 + 3(16) \\ = 46 + 12 + 48 = 106 \text{ g}$$

$$\Rightarrow 0.025 \text{ moles Na}_2\text{CO}_3 = 0.025 \times 106 = 2.65 \text{ g}$$

$$\Rightarrow \text{Mass of water of crystallisation} = 7.16 - 2.65 \\ = 4.51 \text{ g}$$

$$\% \text{ Water of crystallisation} = \frac{4.51}{7.16} \times 100 = 62.99\%$$

**(b)** Next, calculate the value of x in the formula  $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$ . Note from above that by dissolving 7.16 g of the crystals of  $\text{Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O}$  in  $250 \text{ cm}^3$  of solution, we obtain a solution which contains 0.025 moles.

Therefore,  $0.025 \text{ moles Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O} = 7.16 \text{ g}$

$$1 \text{ mole Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O} = \frac{7.16}{0.025} = 286.4$$

$$\begin{aligned} \text{i.e. Rel. mol mass of Na}_2\text{CO}_3 \cdot x\text{H}_2\text{O} &= 286.4 \\ \Rightarrow 2(23) + 12 + 3(16) + x(2 + 16) &= 286.4 \\ 106 + 18x &= 286.4 \\ \text{solve for x} & \\ 18x &= 180.4 \end{aligned}$$

$$x = 10.02 \approx 10$$

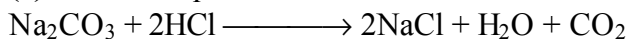
*i.e.* formula is  $\text{Na}_2\text{CO}_3 \cdot 10\text{H}_2\text{O}$

Answers: (a) % Water of crystallisation = 62.99%

(b) x = 10

**13.16**

(a) Balanced equation:



Given:

$$V_a = 22.8 \text{ cm}^3$$

$$M_a = 0.11 \text{ M}$$

$$n_a = 2$$

$$V_b = 25 \text{ cm}^3$$

$$M_b = ?$$

$$n_b = 1$$

	HCl		Na <sub>2</sub> CO <sub>3</sub>
	$\frac{V_a \times M_a}{n_a}$	=	$\frac{V_b \times M_b}{n_b}$
	$\frac{22.8 \times 0.11}{2}$	=	$\frac{25 \times M_b}{1}$

$$\Rightarrow M_b = \frac{22.8 \times 0.11}{25 \times 2}$$

$$= 0.0502 \text{ moles/L}$$

$$0.0502 \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O/L} = (0.0502 / 2) \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O} / 500 \text{ cm}^3$$

$$= 0.0251 \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O} / 500 \text{ cm}^3$$

$$1 \text{ mole Na}_2\text{CO}_3 = 2(23) + 12 + 3(16)$$

$$= 46 + 12 + 48 = 106 \text{ g}$$

$$\Rightarrow 0.0251 \text{ moles Na}_2\text{CO}_3 = 0.0251 \times 106 = 2.66 \text{ g}$$

$$\Rightarrow \text{Mass of water of crystallisation} = 3.55 - 2.66$$

$$= 0.89 \text{ g}$$

$$0.89$$

$$\% \text{ Water of crystallisation} = \frac{0.89}{3.55} \times 100 = 25.07\%$$

(b) Next, calculate the value of x in the formula Na<sub>2</sub>CO<sub>3</sub> xH<sub>2</sub>O. Note from above that by dissolving 3.55 g of the crystals of Na<sub>2</sub>CO<sub>3</sub> xH<sub>2</sub>O in 500 cm<sup>3</sup> of solution, we obtain a solution which contains 0.0251 moles.

$$\text{Therefore, } 0.0251 \text{ moles Na}_2\text{CO}_3 \text{ xH}_2\text{O} = 3.55 \text{ g}$$

$$1 \text{ mole Na}_2\text{CO}_3 \text{ xH}_2\text{O} = \frac{3.55}{0.0251} = 141.43$$

$$\text{i.e. Rel. mol mass of Na}_2\text{CO}_3 \text{ xH}_2\text{O} = 141.43$$

$$\Rightarrow 2(23) + 12 + 3(16) + x(2 + 16) = 141.43$$

$$106 + 18x = 141.43$$

solve for x

$$18x = 35.43$$

$$x = 1.97 \approx 2$$

i.e. formula is Na<sub>2</sub>CO<sub>3</sub>.2H<sub>2</sub>O

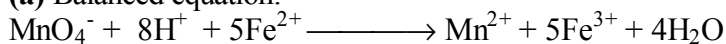
Answers: (a) % Water of crystallisation = 25.07%

(b) x = 2

## Chapter 15 Volumetric Analysis: Oxidation-Reduction

### 15.1

(a) Balanced equation:



Given:

$$V_o = 22.85 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 25 \text{ cm}^3$$

$$M_{\text{red}} = 0.15 \text{ M}$$

$$n_r = 5$$

$\text{MnO}_4^-$	=	$\text{Fe}^{2+}$
$\frac{V_o \times M_o}{n_o}$	=	$\frac{V_r \times M_{\text{red}}}{n_r}$
$\frac{22.85 \times M_o}{1}$	=	$\frac{25 \times 0.15}{5}$

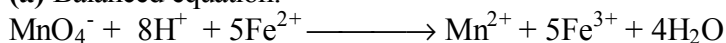
$$\begin{aligned} \Rightarrow M_o &= \frac{25 \times 0.15}{5 \times 22.85} \\ &= 0.0328 \text{ moles/L} \\ &= 0.0328 \times 158 \text{ (} M_r \text{ KMnO}_4 = 158) \\ &= 5.18 \text{ g/L} \end{aligned}$$

Answer: (a) 0.0328 moles/L

(b) 5.18 g / L

### 15.2

(a) Balanced equation:



Given:

$$V_o = 23.45 \text{ cm}^3$$

$$M_o = 0.02 \text{ M}$$

$$n_o = 1$$

$$V_r = 25 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 5$$

$\text{MnO}_4^-$	=	$\text{Fe}^{2+}$
$\frac{V_o \times M_o}{n_o}$	=	$\frac{V_r \times M_{\text{red}}}{n_r}$
$\frac{23.45 \times 0.02}{1}$	=	$\frac{25 \times M_{\text{red}}}{5}$

$$\begin{aligned} \Rightarrow M_{\text{red}} &= \frac{23.45 \times 0.02 \times 5}{25} \\ &= 0.0938 \text{ moles/L} \\ &= 0.0938 \times 278 \text{ (} M_r \text{ FeSO}_4 \cdot 7\text{H}_2\text{O} = 278) \\ &= 26.08 \text{ g/L} \end{aligned}$$

Answer: (a) 0.0938 moles/L

(b) 26.08 g/L

### 15.3

First calculate concentration of ammonium iron(II) sulfate solution.

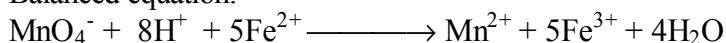
392 g of  $(\text{NH}_4)_2(\text{SO}_4)\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$  in 1 L of solution  $\longrightarrow$  1 M solution

1 g of  $(\text{NH}_4)_2(\text{SO}_4)\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$  in 1 L of solution  $\longrightarrow$   $\frac{1}{392}$  M solution

10.52 g of  $(\text{NH}_4)_2(\text{SO}_4)\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$  in 1 L of solution  $\longrightarrow$   $\frac{1 \times 10.52}{392}$  M solution

10.52 g of  $(\text{NH}_4)_2(\text{SO}_4)\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$  in 250  $\text{cm}^3$  of solution  $\longrightarrow$   $\frac{4 \times 10.52}{392}$  M solution  
 $= 0.1073 \text{ M}$

Balanced equation:



Given:-

$$V_o = 23.8 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 25 \text{ cm}^3$$

$$M_{\text{red}} = 0.1073 \text{ M}$$

$$n_r = 5$$

$$\frac{V_o \times M_o}{n_o} = \frac{V_r \times M_{\text{red}}}{n_r}$$

$$\frac{23.8 \times M_o}{1} = \frac{25 \times 0.1073}{5}$$

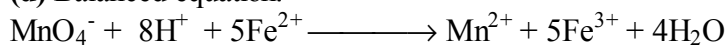
$$\Rightarrow M_o = \frac{25 \times 0.1073}{5 \times 23.8}$$

$$= 0.0225 \text{ moles/L } (M_r \text{ KMnO}_4 = 158)$$

$$= 0.0225 \times 158$$

$$= 3.56 \text{ g/L}$$

Answer: (a) 0.0225 moles/L (b) 3.56 g/L

**15.4****(d)** Balanced equation:

Given:

$$V_o = 21.8 \text{ cm}^3$$

$$M_o = 0.02 \text{ M}$$

$$n_o = 1$$

$$V_r = 25 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 5$$

$$\begin{array}{ccc} & \text{MnO}_4^- & \text{Fe}^{2+} \\ & \frac{V_o \times M_o}{n_o} & = \frac{V_r \times M_{\text{red}}}{n_r} \\ & \frac{21.8 \times 0.02}{1} & = \frac{25 \times M_{\text{red}}}{5} \end{array}$$

$$\Rightarrow M_{\text{red}} = \frac{21.8 \times 0.02 \times 5}{25}$$

$$= 0.0872 \text{ moles/L}$$

$$\begin{aligned} 0.0872 \text{ moles FeSO}_4 \cdot x\text{H}_2\text{O} / \text{L} &= (0.0872 / 4) \text{ moles FeSO}_4 \cdot x\text{H}_2\text{O} / 250 \text{ cm}^3 \\ &= 0.0218 \text{ moles FeSO}_4 \cdot x\text{H}_2\text{O} / 250 \text{ cm}^3 \end{aligned}$$

i.e. by dissolving 6.08 g of the crystals of  $\text{FeSO}_4 \cdot x\text{H}_2\text{O}$  in  $250 \text{ cm}^3$  of solution, we obtain a solution which contains 0.0218 moles.

Therefore,  $0.0218 \text{ moles FeSO}_4 \cdot x\text{H}_2\text{O} = 6.08 \text{ g}$

$$1 \text{ mole FeSO}_4 \cdot x\text{H}_2\text{O} = \frac{6.08}{0.0218} = 278.90$$

$$\Rightarrow 56 + 32 + 4(16) + x(2 + 16) = 278.90$$

$$152 + 18x = 278.90$$

$$18x = 126.9$$

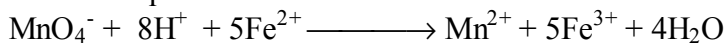
$$x = 7.05 \approx 7$$

i.e. formula is  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$

Answer:  $x = 7$

### 15.5

Balanced equation:



Given:

$$V_o = 23.85 \text{ cm}^3$$

$$M_o = 0.021 \text{ M}$$

$$n_o = 1$$

$$V_{\text{red}} = 25 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 5$$

$$\begin{array}{ccc} \text{MnO}_4^- & & \text{Fe}^{2+} \\ \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_{\text{red}}}{n_r} \\ \frac{23.85 \times 0.021}{1} & = & \frac{25 \times M_{\text{red}}}{5} \end{array}$$

$$\Rightarrow M_{\text{red}} = \frac{23.85 \times 0.021 \times 5}{25}$$

$$= 0.1002 \text{ moles/L}$$

$$\begin{aligned} 0.1002 \text{ moles (NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot x\text{H}_2\text{O} / \text{L} &= (0.1002 / 4) \text{ moles (NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot x\text{H}_2\text{O} / 250 \text{ cm}^3 \\ &= 0.0251 \text{ moles (NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot x\text{H}_2\text{O} / 250 \text{ cm}^3 \end{aligned}$$

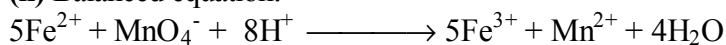
i.e. by dissolving 9.8 g of the crystals of  $(\text{NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot x\text{H}_2\text{O}$  in  $250 \text{ cm}^3$  of solution, we obtain a solution which contains 0.0251 moles.

Therefore,  $0.0251 \text{ moles (NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot x\text{H}_2\text{O} = 9.8 \text{ g}$

$$1 \text{ mole (NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot x\text{H}_2\text{O} = \frac{9.8}{0.0251} = 390.44$$

$$\begin{aligned} \Rightarrow 2(14) + 8(1) + 32 + 4(16) + 56 + 32 + 4(16) + x(2 + 16) &= 390.44 \\ 284 + 18x &= 390.44 \\ 18x &= 106.44 \\ x &= 5.91 \approx 6 \end{aligned}$$

i.e. formula is  $(\text{NH}_4)_2 \text{ SO}_4\text{FeSO}_4 \cdot 6\text{H}_2\text{O}$

**15.6****(ii)** Balanced equation:

Given:-

$$V_o = 20 \text{ cm}^3$$

$$M_o = 0.02 \text{ M}$$

$$n_o = 1$$

$$V_r = 25 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 5$$

$\text{MnO}_4^-$	$\text{Fe}^{2+}$
$\frac{V_o \times M_o}{n_o}$	$= \frac{V_r \times M_{\text{red}}}{n_r}$
$\frac{20 \times 0.02}{1}$	$= \frac{25 \times M_{\text{red}}}{5}$

$$\Rightarrow M_r = \frac{20 \times 0.02 \times 5}{25}$$

$$= 0.08 \text{ moles/L}$$

**(iii)**

$$0.08 \text{ moles FeSO}_4(\text{NH}_4)_2 \text{SO}_4 \cdot x\text{H}_2\text{O/L} = (0.08 / 4) \text{ moles FeSO}_4(\text{NH}_4)_2 \text{SO}_4 \cdot x\text{H}_2\text{O}/250\text{cm}^3$$

$$= 0.02 \text{ moles FeSO}_4(\text{NH}_4)_2 \text{SO}_4 \cdot x\text{H}_2\text{O} / 250 \text{ cm}^3$$

i.e. by dissolving 7.84 g of the crystals of  $(\text{NH}_4)_2 \text{SO}_4 \text{FeSO}_4 \cdot x\text{H}_2\text{O}$  in  $250 \text{ cm}^3$  of solution, we obtain a solution which contains 0.02 moles.

Therefore,  $0.02 \text{ moles } (\text{NH}_4)_2 \text{SO}_4 \text{FeSO}_4 \cdot x\text{H}_2\text{O} = 7.84 \text{ g}$

$$1 \text{ mole } (\text{NH}_4)_2 \text{SO}_4 \text{FeSO}_4 \cdot x\text{H}_2\text{O} = \frac{7.84}{0.02} = 392$$

$$\Rightarrow 56 + 32 + 4(16) + 2(14) + 8(1) + 32 + 4(16) + x(2 + 16) = 392$$

$$284 + 18x = 392$$

$$18x = 108$$

$$x = 6$$

i.e. formula is  $\text{FeSO}_4(\text{NH}_4)_2 \text{SO}_4 \cdot 6\text{H}_2\text{O}$

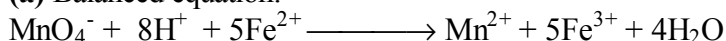
Answers : (ii) 0.08 moles/L

(iii)  $x = 6$

**15.7**

(iii)

(a) Balanced equation:



Given:-

$$V_o = 9.15 \text{ cm}^3$$

$$M_o = 0.01 \text{ M}$$

$$n_o = 1$$

$$V_r = 20 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 5$$

$$\begin{array}{ccc} \text{MnO}_4^- & & \text{Fe}^{2+} \\ \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_{\text{red}}}{n_r} \\ \frac{9.15 \times 0.01}{1} & = & \frac{20 \times M_{\text{red}}}{5} \\ & & \Rightarrow M_{\text{red}} = \frac{9.15 \times 0.01 \times 5}{20} \end{array}$$

$$= 0.0229 \text{ moles / L}$$

$$= 0.0229 \times 152$$

$$= 3.48 \text{ g / L}$$

(Rel. mol mass  $\text{FeSO}_4 = 56 + 32 + 4(16) = 152$ )

Therefore, in the  $250 \text{ cm}^3$  volumetric flask there are  $3.48 / 4 \text{ g} = 0.87 \text{ g FeSO}_4$

i.e. 5 tablets contain  $0.87 \text{ g FeSO}_4$

$\Rightarrow$  1 tablet contains  $(0.87 / 5) \text{ g} = 0.174 \text{ g FeSO}_4$

(b)

$$\% \text{ of Fe in FeSO}_4 = \frac{\text{Rel. atomic mass Fe}}{\text{Rel. mol. mass FeSO}_4} \times 100$$

$$= \frac{56}{152} \times 100 = 36.84\%$$

$\Rightarrow$  Mass of Fe in each tablet = 36.84% of  $0.174 \text{ g}$

$$= \frac{36.84}{100} \times 0.174 = 0.064 \text{ g}$$

(c)

$$\text{Mass of 1 tablet} = \frac{1.69}{5} = 0.338 \text{ g}$$

$$\% \text{ FeSO}_4 \text{ in each tablet} = \frac{\text{Mass of FeSO}_4 \text{ in tablet}}{\text{Mass of 1 tablet}} \times 100$$



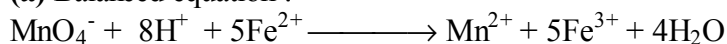
$$= \frac{0.174}{0.338} \times 100 = 51.48 \%$$

Answer: (iii) (a) 0.174 g      (b) 0.064 g      (c) 51.48%

### 15.8

(iv)

(a) Balanced equation :-



Given:-

$$V_o = 4.51 \text{ cm}^3$$

$$M_o = 0.015 \text{ M}$$

$$n_o = 1$$

$$V_r = 25 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 5$$

$$\begin{array}{ccc} \text{MnO}_4^- & & \text{Fe}^{2+} \\ V_o \times M_o & = & V_r \times M_{\text{red}} \\ \hline n_o & = & n_r \\ \hline 4.51 \times 0.015 & = & 25 \times M_{\text{red}} \\ \hline 1 & = & 5 \end{array}$$

$$\Rightarrow M_{\text{red}} = \frac{4.51 \times 0.015 \times 5}{25}$$

$$= 0.0135 \text{ moles / L}$$

$$= 0.0135 \times 152$$

$$= 2.05 \text{ g / L}$$

(Rel. molecular mass  $\text{FeSO}_4 = 56 + 32 + 4(16) = 152$ )

Therefore, in the  $250 \text{ cm}^3$  volumetric flask there are  $2.05 / 4 \text{ g} = 0.513 \text{ g FeSO}_4$

i.e. 4 tablets contain  $0.513 \text{ g FeSO}_4$

$\Rightarrow$  1 tablet contains  $(0.513 / 4) \text{ g} = 0.128 \text{ g FeSO}_4$

(b)

$$\% \text{ of Fe in FeSO}_4 = \frac{\text{Rel. atomic mass Fe}}{\text{Rel. mol. mass FeSO}_4} \times 100$$

$$= \frac{56}{152} \times 100 = 36.84 \%$$

$\Rightarrow$  Mass of Fe in each tablet = 36.84 % of 0.128 g

$$= \frac{36.84}{100} \times 0.128 = 0.047 \text{ g}$$

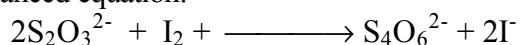
$$(c) \quad \text{Mass of 1 tablet} = \frac{0.96}{4} = 0.24 \text{ g}$$

$$\begin{aligned} \% \text{ FeSO}_4 \text{ in each tablet} &= \frac{\text{Mass of FeSO}_4 \text{ in tablet}}{\text{Mass of 1 tablet}} \times 100 \\ &= \frac{0.128}{0.24} \times 100 = 53.33\% \end{aligned}$$

Answer: (iv) (a) 0.128 g (b) 0.047 g (c) 53.33%

### 15.9

(a) Balanced equation:



Given:-

$$V_o = 25 \text{ cm}^3$$

$$M_o = 0.05 \text{ M}$$

$$n_o = 1$$

$$V_r = 18.55 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 2$$

$$\begin{array}{ccc} \text{I}_2 & & \text{S}_2\text{O}_3^{2-} \\ \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_{\text{red}}}{n_r} \\ \frac{25 \times 0.05}{1} & = & \frac{18.55 \times M_{\text{red}}}{2} \end{array}$$

$$\Rightarrow M_{\text{red}} = \frac{25 \times 0.05 \times 2}{18.55}$$

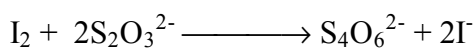
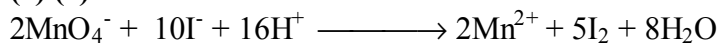
$$= 0.1348 \text{ moles/L}$$

$$= 0.1348 \times 248$$

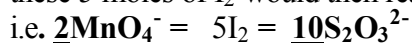
$$= 33.43 \text{ g/L}$$

(Rel molecular mass  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O} = 248$ )

Answer: (a) 0.1348 moles/L, (b) 33.43 g/L

**15.10****(v) (a)**

From the balanced equations, we see that 2 moles of  $\text{MnO}_4^-$  produce five moles of  $\text{I}_2$  and these 5 moles of  $\text{I}_2$  would then react with 10 moles of  $\text{S}_2\text{O}_3^{2-}$ .



Given:

$$V_o = 25 \text{ cm}^3$$

$$M_o = 0.018 \text{ M}$$

$$n_o = 2$$

$$V_r = 15.6 \text{ cm}^3$$

$$M_{\text{red}} = ?$$

$$n_r = 10$$

$\text{MnO}_4^-$	$\text{S}_2\text{O}_3^{2-}$
$\frac{V_o \times M_o}{n_o}$	$= \frac{V_r \times M_{\text{red}}}{n_r}$
$\frac{25 \times 0.018}{2}$	$= \frac{15.6 \times M_{\text{red}}}{10}$

$$\Rightarrow M_{\text{red}} = \frac{25 \times 0.018 \times 10}{2 \times 15.6}$$

$$= 0.1442 \text{ moles/L}$$

$$= 0.1442 \times 248$$

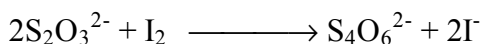
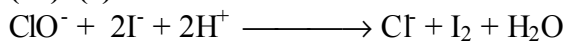
$$= 35.76 \text{ g/L}$$

(Rel molecular mass  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O} = 248$ )

Answer: (a) 0.1442 moles/L, (b) 35.76 g/L

**15.11**

(vii) (a)



From the balanced equations, we see that 1 mole of  $\text{ClO}^-$  produce 1 moles of  $\text{I}_2$  and this 1 mole of  $\text{I}_2$  would then react with 2 moles of  $\text{S}_2\text{O}_3^{2-}$ .

i.e.  $\underline{1}\text{ClO}^- = 1\text{I}_2 = \underline{2}\text{S}_2\text{O}_3^{2-}$

Given:

$$V_o = 25 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 22.4 \text{ cm}^3$$

$$M_{\text{red}} = 0.22 \text{ M}$$

$$n_r = 2$$

$\text{ClO}^-$		$\text{S}_2\text{O}_3^{2-}$
$V_o \times M_o$	=	$V_r \times M_{\text{red}}$
<hr style="width: 100%;"/>		<hr style="width: 100%;"/>
$n_o$		$n_r$
 $25 \times M_o$	 =	 $22.4 \times 0.22$
<hr style="width: 100%;"/>		<hr style="width: 100%;"/>
1		2

$$\Rightarrow M_o = \frac{22.4 \times 0.22}{2 \times 25}$$

$$= 0.0986 \text{ moles / L}$$

$$\Rightarrow \text{Concentration of original solution} = 0.0986 \times 10 \text{ (10 times more concentrated)}$$

$$= 0.986 \text{ M}$$

$$= 0.986 \times 74.5$$

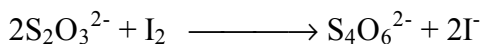
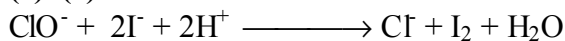
$$= 73.46 \text{ g/L}$$

$$= 7.346 \text{ g/100 cm}^3$$

$$= 7.35 \% \text{ w/v}$$

Answer: (a) 0.986 moles/L, (b) 73.46 g/L, (c) 7.35% w/v.

(c) Concentration of NaClO in w/v

**15.12****(v) (a)**

From the balanced equations, we see that 1 mole of  $\text{ClO}^-$  produce 1 moles of  $\text{I}_2$  and this 1 mole of  $\text{I}_2$  would then react with 2 moles of  $\text{S}_2\text{O}_3^{2-}$ .

i.e.  $\underline{1}\text{ClO}^- = 1\text{I}_2 = \underline{2}\text{S}_2\text{O}_3^{2-}$

Given:

$$V_o = 25 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = \frac{24.9 + 25}{2} = 24.95 \text{ cm}^3$$

$$M_{\text{red}} = 0.1 \text{ M}$$

$$n_r = 2$$

$$\begin{array}{ccc} \text{ClO}^- & & \text{S}_2\text{O}_3^{2-} \\ \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_{\text{red}}}{n_r} \\ \frac{25 \times M_o}{1} & = & \frac{24.95 \times 0.1}{2} \end{array}$$

$$\Rightarrow M_o = \frac{24.95 \times 0.1}{2 \times 25}$$

$$\begin{array}{l} \text{Concentration of original solution} \\ = 0.0499 \text{ moles/L} \\ = 0.0499 \times 10 \text{ moles/L} \\ = 0.499 \text{ moles/L} \\ = 0.499 \times 74.5 \text{ g/L } (M_r \text{ NaClO} = 74.5) \\ = 37.18 \text{ g/L} \\ = 3.718 \text{ g/100 cm}^3 \\ = 3.72 \% \text{ w / v} \end{array}$$

Answer: (a) 0.499 moles/L, (b) 37.18 g/L, (c) 3.72%

## Chapter 16 – Rates of Reaction

### 16.3

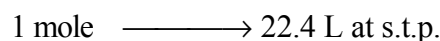
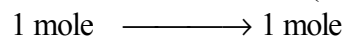
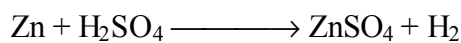
- (i) graph  
 (ii) 210 seconds - the reaction is complete at a time of 210 seconds as after this time, the volume of O<sub>2</sub> evolved remains constant at 200 cm<sup>3</sup>.

(iii) Fraction of H<sub>2</sub>O<sub>2</sub> decomposed in first minute =  $\frac{150}{200} = \frac{3}{4}$

### 16.5

- (ii)

$$\begin{aligned} \text{number of moles of H}_2\text{SO}_4 &= \frac{V \times M}{1000} \\ &= \frac{25 \times 0.1}{1000} = 2.5 \times 10^{-3} \end{aligned}$$



$$\begin{aligned} \text{i.e. } 2.5 \times 10^{-3} \text{ mole H}_2\text{SO}_4 &\longrightarrow (2.5 \times 10^{-3} \times 22.4) \text{ L of H}_2 \text{ at s.t.p.} \\ &= 0.056 \text{ L of H}_2 \\ &= 56 \text{ cm}^3 \end{aligned}$$

- (iv) graph

- (iv) Some sample results from the graph:

$$\text{Instantaneous rate of reaction at 2 minutes} = \frac{54.5 - 35.5}{3 - 1} = \frac{19}{2} = 9.5 \text{ cm}^3 / \text{minute}$$

Any value between 9.5 – 11 cm<sup>3</sup>/min is acceptable.

## Chapter 17 – Chemical Equilibrium

### 17.6

	$\text{CH}_3\text{COOH}$	+ $\text{C}_2\text{H}_5\text{OH}$	$\rightleftharpoons$	$\text{CH}_3\text{COOC}_2\text{H}_5$	+ $\text{H}_2\text{O}$
Initially:	1	1		0	0
At Equil.	0.33	0.33		0.67	0.67
Conc. at equil.	[0.33 / V]	[0.33 / V]		[0.67 / V]	[0.67 / V]

V is the volume of the container which we are not given in the question.

$$K_c = \frac{[\text{CH}_3\text{COOC}_2\text{H}_5][\text{H}_2\text{O}]}{[\text{CH}_3\text{COOH}][\text{C}_2\text{H}_5\text{OH}]} = \frac{(0.67 / V)(0.67 / V)}{(0.33 / V)(0.33 / V)}$$

The V terms cancel out in the K<sub>c</sub> expression

$$\therefore K_c = \frac{(0.67)(0.67)}{(0.33)(0.33)} = 4.12$$

Answer: K<sub>c</sub> = 4.12

### 17.7

	$2\text{HI}$	$\rightleftharpoons$	$\text{H}_2$	+	$\text{I}_2$
Initially	1		0		0
At Equil.	1 – 0.2 = 0.8		0.1		0.1
Conc. at equil. (V = 1 L)	[0.8]		[0.1]		[0.1]

$$K_c = \frac{[\text{H}_2][\text{I}_2]}{[\text{HI}]}$$

$$\Rightarrow K_c = \frac{(0.1)(0.1)}{(0.8)^2} = 0.0156$$

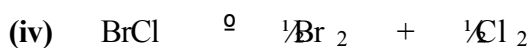
Answer: K<sub>c</sub> = 0.0156

**17.8**

<b>(ii)</b>	$2\text{BrCl}$	$\rightleftharpoons$	$\text{Br}_2$	+	$\text{Cl}_2$
Initially	0.9		0		0
At Equil.	$0.9 - 0.8$ $= 0.1$		0.4		0.4
Conc. at equil. ( $V = 5 \text{ L}$ )	$\frac{0.1}{5}$ $= [0.02]$		$\frac{0.4}{5}$ $= [0.08]$		$\frac{0.4}{5}$ $= [0.08]$

$$K_c = \frac{[\text{Br}_2] [\text{Cl}_2]}{[\text{BrCl}]^2}$$

$$\Rightarrow K_c = \frac{(0.08)(0.08)}{(0.02)^2} = 16$$



$$K'_c = \frac{[\text{Br}_2]^{1/2} [\text{Cl}_2]^{1/2}}{[\text{BrCl}]} = \sqrt{K_c}$$

$$\Rightarrow K'_c = \sqrt{16} = 4$$

Answer: (ii)  $K_c = 16$   
(iv)  $K'_c = 4$



## Chapter 18 – pH and Indicators

### 18.2

$$\text{(a) } \text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (10^{-7}) \\ = 7$$

$$\text{(b) } \text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (4 \times 10^{-3}) \\ = 2.40$$

$$\text{(c) } \text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (2.62 \times 10^{-8}) \\ = 7.58$$

$$\text{(d) } \text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (5.2 \times 10^{-3}) \\ = 2.28$$

$$\text{(e) } \text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (8.7 \times 10^{-11}) \\ = 10.06$$

### 18.3

$$\text{(a) } \text{pH} = -\log_{10} [\text{H}^+] = 5.65 \\ \log_{10} [\text{H}^+] = -5.65 \\ \Rightarrow [\text{H}^+] = \text{antilog} (-5.65) \\ = 2.24 \times 10^{-6} \text{ mol/L}$$

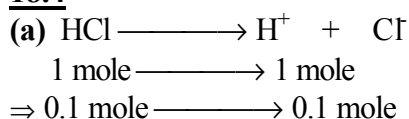
$$\text{(b) } \text{pH} = -\log_{10} [\text{H}^+] = 11.15 \\ \log_{10} [\text{H}^+] = -11.15 \\ \Rightarrow [\text{H}^+] = \text{antilog} (-11.15) \\ = 7.08 \times 10^{-12} \text{ mol/L}$$

$$\text{(c) } \text{pH} = -\log_{10} [\text{H}^+] = 1.09 \\ \log_{10} [\text{H}^+] = -1.09 \\ \Rightarrow [\text{H}^+] = \text{antilog} (-1.09) \\ = 0.08 \text{ mol/L}$$

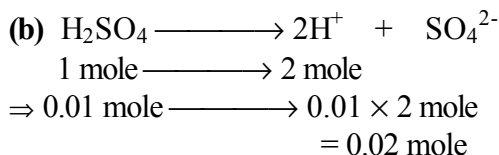
$$\text{(d) } \text{pH} = -\log_{10} [\text{H}^+] = 7 \\ \log_{10} [\text{H}^+] = -7 \\ \Rightarrow [\text{H}^+] = \text{antilog} (-7) \\ = 1 \times 10^{-7} \text{ mol/L}$$

$$\text{(e) } \text{pH} = -\log_{10} [\text{H}^+] = 9.65 \\ \log_{10} [\text{H}^+] = -9.65 \\ \Rightarrow [\text{H}^+] = \text{antilog} (-9.65) \\ = 2.24 \times 10^{-10} \text{ mol/L}$$

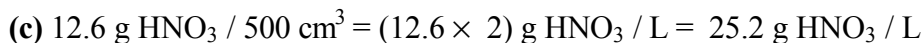
### 18.4



$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (0.1) = 1$$

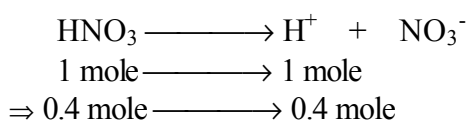


$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (0.02) = 1.70$$

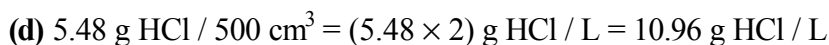


$$\text{Rel molecular mass HNO}_3 = 1 + 14 + 3(16) = 63$$

$$\text{Number of moles of HNO}_3 / \text{L} = \frac{\text{Mass in 1L}}{\text{Rel molecular mass}} = \frac{25.2}{63} = 0.4$$

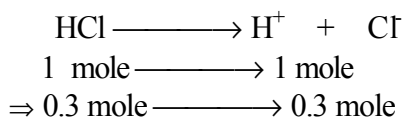


$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (0.4) = 0.40$$



$$\text{Rel molecular mass HCl} = 1 + 35.5 = 36.5$$

$$\text{Number of moles of HCl} / \text{L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{10.96}{36.5} = 0.3$$

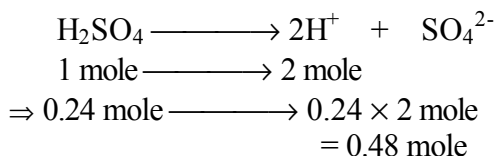


$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (0.3) = 0.52$$

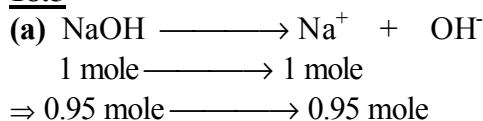


$$\text{Rel molecular mass H}_2\text{SO}_4 = 2(1) + 32 + 4(16) = 98$$

$$\text{Number of moles of H}_2\text{SO}_4 / \text{L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{23.2}{98} = 0.24$$

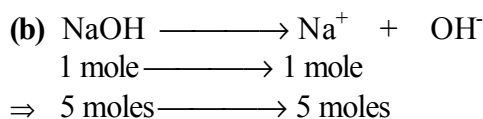


$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (0.48) = 0.32$$

**18.5**

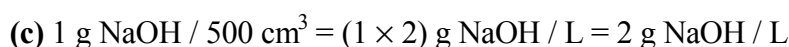
$$\text{pOH} = -\log_{10} [\text{OH}^-] = -\log_{10} (0.95) = 0.02$$

$$\text{pH} = 14 - \text{pOH} = 14 - 0.02 = 13.98$$



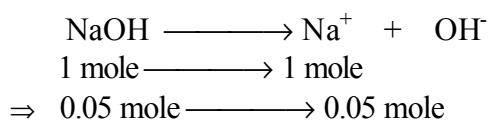
$$\text{pOH} = -\log_{10} [\text{OH}^-] = -\log_{10} (5) = -0.70$$

$$\text{pH} = 14 - \text{pOH} = 14 - (-0.70) = 14.70$$



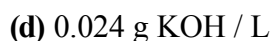
$$\text{Rel molecular mass NaOH} = 23 + 16 + 1 = 40$$

$$\text{Number of moles of NaOH} / \text{L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{2}{40} = 0.05$$



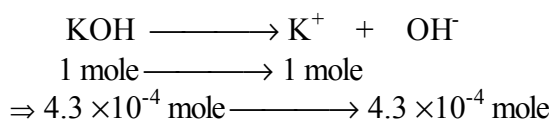
$$\text{pOH} = -\log_{10} [\text{OH}^-] = -\log_{10} (0.05) = 1.30$$

$$\text{pH} = 14 - \text{pOH} = 14 - 1.30 = 12.70$$



$$\text{Rel molecular mass KOH} = 39 + 16 + 1 = 56$$

$$\text{Number of moles of KOH} / \text{L} = \frac{\text{Mass in 1L}}{\text{Rel molecular mass}} = \frac{0.024}{56} = 4.3 \times 10^{-4}$$



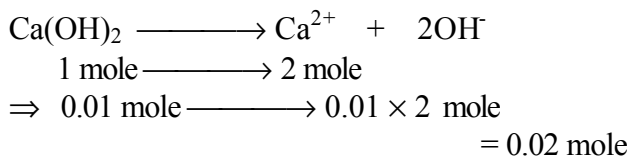
$$\text{pOH} = -\log_{10} [\text{OH}^-] = -\log_{10} (4.3 \times 10^{-4}) = 3.37$$

$$\text{pH} = 14 - \text{pOH} = 14 - 3.37 = 10.63$$

$$(e) 0.37 \text{ g Ca(OH)}_2 / 500 \text{ cm}^3 = (0.37 \times 2) \text{ g Ca(OH)}_2 / \text{L} = 0.74 \text{ g Ca(OH)}_2 / \text{L}$$

$$\text{Rel molecular mass Ca(OH)}_2 = 40 + 2(16) + 2(1) = 74$$

$$\text{Number of moles of Ca(OH)}_2 / \text{L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{0.74}{74} = 0.01$$



$$\text{pOH} = -\log_{10} [\text{OH}^-] = -\log_{10} (0.02) = 1.70$$

$$\text{pH} = 14 - \text{pOH} = 14 - 1.70 = 12.30$$

### 18.6

$$(ii) 0.3 \text{ g CH}_3\text{COOH} / 50 \text{ cm}^3 = (0.3 \times 20) \text{ g CH}_3\text{COOH} / \text{L} = 6 \text{ g CH}_3\text{COOH} / \text{L}$$

$$\text{Rel molecular mass CH}_3\text{COOH} = 12 + 3(1) + 12 + 2(16) + 1 = 60$$

$$\text{Number of moles of CH}_3\text{COOH} / \text{L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{6}{60} = 0.1$$

Hydrogen ion concentration can be found by substituting into the formula:-

$$\begin{aligned} [\text{H}^+] &= \sqrt{K_a \times M_{\text{acid}}} \\ &= \sqrt{1.8 \times 10^{-5} \times 0.1} \\ &= 1.34 \times 10^{-3} \text{ mol/L} \end{aligned}$$

$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (1.34 \times 10^{-3}) = 2.87$$

Answer: pH = 2.87

### 18.7

$$5 \times 10^{-2} \text{ mole HA} / 100 \text{ cm}^3 = (5 \times 10^{-2} \times 10) \text{ mole HA} / \text{L} = 0.5 \text{ mole HA} / \text{L}$$

$$\begin{aligned} [\text{H}^+] &= \sqrt{K_a \times M_{\text{acid}}} \\ &= \sqrt{5.5 \times 10^{-5} \times 0.5} \\ &= \sqrt{2.75 \times 10^{-5}} \\ &= 5.24 \times 10^{-3} \text{ mol/L} \end{aligned}$$

$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (5.24 \times 10^{-3}) = 2.28$$

Answer: pH = 2.28

**18.8**

Hydrogen ion concentration can be found by substituting into the formula:-

$$\begin{aligned}
 [\text{H}^+] &= \sqrt{K_a \times M_{\text{acid}}} \\
 &= \sqrt{1.8 \times 10^{-5} \times 0.1} \\
 &= \sqrt{1.8 \times 10^{-6}} \\
 &= 1.34 \times 10^{-3} \text{ mol/L}
 \end{aligned}$$

Answer:  $1.34 \times 10^{-3} \text{ mol/L}$

**18.9**

$$\begin{aligned}
 \text{pH} &= -\log_{10} [\text{H}^+] = 2.37 \\
 \log_{10} [\text{H}^+] &= -2.37 \\
 \Rightarrow [\text{H}^+] &= \text{antilog}(-2.37) \\
 &= 4.27 \times 10^{-3} \text{ mol/L}
 \end{aligned}$$

$K_a$  can be found by substituting into the formula:-

$$\begin{aligned}
 [\text{H}^+] &= \sqrt{K_a \times M_{\text{acid}}} \\
 \text{Square both sides} \\
 [\text{H}^+]^2 &= K_a \times M_{\text{acid}} \\
 (4.27 \times 10^{-3})^2 &= K_a \times 1 \\
 \Rightarrow K_a &= 1.8 \times 10^{-5}
 \end{aligned}$$

$$\begin{aligned}
 [\text{H}^+] &= \sqrt{K_a \times M_{\text{acid}}} \\
 &= \sqrt{1.8 \times 10^{-5} \times 0.05} \\
 &= \sqrt{9 \times 10^{-7}} \\
 &= 9.49 \times 10^{-4} \text{ mol/L}
 \end{aligned}$$

$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (9.49 \times 10^{-4}) = 3.02$$

Answer:  $[\text{H}^+] = 4.27 \times 10^{-3} \text{ mol/L}$   
 $\text{pH} = 3.02$

### 18.10

1M methanoic acid is 1.3% dissociated i.e. 1.3% of 1 mole

$$= \frac{1.3}{100} \times 1 = 0.013 \text{ mole of } \text{H}^+ \text{ ions are formed}$$

$K_a$  can be found by substituting into the formula:

$$[\text{H}^+] = \sqrt{K_a \times M_{\text{acid}}}$$

Square both sides

$$[\text{H}^+]^2 = K_a \times [\text{acid}]$$

$$(0.013)^2 = K_a \times 1$$

$$\begin{aligned} \Rightarrow K_a &= 1.69 \times 10^{-4} \\ &= 1.7 \times 10^{-4} \end{aligned}$$

$$\text{pH} = -\log_{10} [\text{H}^+] = -\log_{10} (0.013) = 1.89$$

Answer: pH = 1.89

### 18.11

$$1.5 \text{ g } \text{C}_2\text{H}_5\text{NH}_2 / 250 \text{ cm}^3 = (1.5 \times 4) \text{ g } \text{C}_2\text{H}_5\text{NH}_2 / \text{L} = 6 \text{ g } \text{C}_2\text{H}_5\text{NH}_2 / \text{L}$$

$$\text{Rel molecular mass } \text{C}_2\text{H}_5\text{NH}_2 = 2(12) + 5(1) + 14 + 2(1) = 45$$

$$\text{Number of moles of } \text{C}_2\text{H}_5\text{NH}_2 / \text{L} = \frac{\text{Mass in 1 L}}{\text{Rel molecular mass}} = \frac{6}{45} = 0.133$$

Hydroxide ion concentration can be found by substituting into the formula:

$$[\text{OH}^-] = \sqrt{K_b \times M_{\text{base}}}$$

$$= \sqrt{4.4 \times 10^{-4} \times 0.133}$$

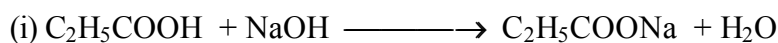
$$= \sqrt{5.852 \times 10^{-5}}$$

$$= 7.65 \times 10^{-3} \text{ mol/L}$$

$$\text{pOH} = -\log_{10} [\text{OH}^-] = -\log_{10} (7.65 \times 10^{-3}) = 2.12$$

$$\text{pH} = 14 - \text{pOH} = 14 - 2.12 = 11.88$$

Answer: pH = 11.88

**18.13**

Ethanoic acid

$V_a = 25 \text{ cm}^3$

$M_a = 0.1 \text{ M}$

$n_a = 1$

Sodium Hydroxide

$V_b = ? \text{ cm}^3$

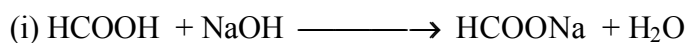
$M_b = 0.1 \text{ M}$

$n_b = 1$

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{25 \times 0.1}{1} = \frac{V_b \times 0.1}{1}$$

$$V_b = \frac{25 \times 0.1}{0.1} = 25 \text{ cm}^3$$

Answer:  $25 \text{ cm}^3$ **18.17**

Methanoic acid

$V_a = ? \text{ cm}^3$

$M_a = 0.1 \text{ M}$

$n_a = 1$

Sodium Hydroxide

$V_b = 25 \text{ cm}^3$

$M_b = 0.108 \text{ M}$

$n_b = 1$

$$\frac{V_a \times M_a}{n_a} = \frac{V_b \times M_b}{n_b}$$

$$\frac{V_a \times 0.1}{1} = \frac{25 \times 0.108}{1}$$

$$V_a = \frac{25 \times 0.108}{0.1} = 27 \text{ cm}^3$$

Answer:  $27 \text{ cm}^3$

## Chapter 19 – Environmental Chemistry – Water

Teachers may wonder why the sequence of steps involved in water treatment (pages 269 – 271 in textbook) is slightly different from that studied at Junior Certificate level in *The World of Science* (page 233). As a result of increased demand for water in recent years, modern water treatment plants do not have the capacity to store vast quantities of water. Therefore, flocculation is now carried out **before** settlement rather than first storing the water, allowing particles to settle and then carrying out flocculation.

### 19.3

Given:-

$$V_{\text{Ca}} = 100 \text{ cm}^3$$

$$M_{\text{Ca}} = ?$$

$$n_{\text{Ca}} = 1$$

$$V_{\text{ed}} = 25 \text{ cm}^3$$

$$M_{\text{ed}} = 0.025 \text{ M}$$

$$n_{\text{ed}} = 1$$

$$\begin{array}{ccc} \text{Ca}^{2+} & & \text{edta} \\ \frac{V_{\text{Ca}} \times M_{\text{Ca}}}{n_{\text{Ca}}} = & & \frac{V_{\text{ed}} \times M_{\text{ed}}}{n_{\text{ed}}} \\ \frac{100 \times M_{\text{Ca}}}{1} = & & \frac{25 \times 0.025}{1} \end{array}$$

$$\Rightarrow M_{\text{Ca}} = \frac{25 \times 0.025}{100}$$

$$\begin{aligned} &= 6.25 \times 10^{-3} \text{ moles/L CaCO}_3 \\ &= 6.25 \times 10^{-3} \times 100 \text{ g/L CaCO}_3 \quad (M_r \text{ CaCO}_3 = 100) \\ &= 0.625 \text{ g/L CaCO}_3 \\ &= 0.625 \times 1,000 \text{ mg/L CaCO}_3 \\ &= 625 \text{ mg/L CaCO}_3 \\ &= 625 \text{ p.p.m. CaCO}_3 \end{aligned}$$

Answer: Total hardness of water = 625 p.p.m.

### 19.4

(vi) Total hardness

Given:-

$$V_{\text{Ca}} = 100 \text{ cm}^3$$

$$M_{\text{Ca}} = ?$$

$$n_{\text{Ca}} = 1$$

$$V_{\text{ed}} = 19 \text{ cm}^3$$

$$M_{\text{ed}} = 0.01 \text{ M}$$

$$n_{\text{ed}} = 1$$

$$\begin{array}{ccc} \text{Ca}^{2+} & & \text{edta} \\ \frac{V_{\text{Ca}} \times M_{\text{Ca}}}{n_{\text{Ca}}} = & & \frac{V_{\text{ed}} \times M_{\text{ed}}}{n_{\text{ed}}} \\ \frac{100 \times M_{\text{Ca}}}{1} = & & \frac{19 \times 0.01}{1} \end{array}$$



$$\begin{aligned}
 \Rightarrow M_{\text{Ca}} &= \frac{19 \times 0.01}{100} \\
 &= 1.9 \times 10^{-3} \text{ moles/L CaCO}_3 \\
 &= 1.9 \times 10^{-3} \times 100 \text{ g/L CaCO}_3 \text{ (} M_r \text{ CaCO}_3 = 100\text{)} \\
 &= 0.19 \text{ g/L CaCO}_3 \\
 &= 0.19 \times 1000 \text{ mg/L CaCO}_3 \\
 &= 190 \text{ mg/L CaCO}_3 \\
 &= 190 \text{ p.p.m. CaCO}_3
 \end{aligned}$$

**Permanent hardness**

Given:-

$$V_{\text{Ca}} = 100 \text{ cm}^3$$

$$M_{\text{Ca}} = ?$$

$$n_{\text{Ca}} = 1$$

$$V_{\text{ed}} = 6 \text{ cm}^3$$

$$M_{\text{ed}} = 0.01 \text{ M}$$

$$n_{\text{ed}} = 1$$

$\text{Ca}^{2+}$	edta
$\frac{V_{\text{Ca}} \times M_{\text{Ca}}}{n_{\text{Ca}}}$	$= \frac{V_{\text{ed}} \times M_{\text{ed}}}{n_{\text{ed}}}$
$\frac{100 \times M_{\text{Ca}}}{1}$	$= \frac{6 \times 0.01}{1}$

$$\begin{aligned}
 \Rightarrow M_{\text{Ca}} &= \frac{6 \times 0.01}{100} \\
 &= 6 \times 10^{-4} \text{ moles/L CaCO}_3 \\
 &= 6 \times 10^{-4} \times 100 \text{ g/L CaCO}_3 \text{ (} M_r \text{ CaCO}_3 = 100\text{)} \\
 &= 0.06 \text{ g/L CaCO}_3 \\
 &= 0.06 \times 1000 \text{ mg/L CaCO}_3 \\
 &= 60 \text{ mg/L CaCO}_3 \\
 &= 60 \text{ p.p.m. CaCO}_3
 \end{aligned}$$

Hardness due to calcium hydrogen carbonate (temporary)

$$= \text{Total hardness} - \text{Permanent hardness}$$

$$= 190 - 60 = 130 \text{ p.p.m.}$$

Answer: Total hardness of water = 190 p.p.m.

Hardness due to calcium hydrogen carbonate = 130 p.p.m.

**19.6**

$$\begin{aligned}\text{Total suspended solids} &= 0.52 \text{ g} / 250 \text{ cm}^3 \\ &= 0.52 \times 4 \text{ g/L} \\ &= 0.52 \times 4 \times 1,000 \text{ mg/L} \\ &= 2080 \text{ p.p.m.}\end{aligned}$$

$$\begin{aligned}\text{Total dissolved solids} &= 0.34 \text{ g} / 100 \text{ cm}^3 \\ &= 0.34 \times 10 \text{ g/L} \\ &= 0.34 \times 10 \times 1,000 \text{ mg/L} \\ &= 3400 \text{ p.p.m.}\end{aligned}$$

Answer: Total suspended solids = 2080 p.p.m.  
Total dissolved solids = 3400 p.p.m.

**19.7**

Given:-

$$V_o = 100 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 8.8 \text{ cm}^3$$

$$M_r = 0.02 \text{ M}$$

$$n_r = 4$$

$$\begin{array}{ccc}
 \text{O}_2 & & \text{S}_2\text{O}_3^{2-} \\
 \\
 \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_r}{n_r} \\
 \\
 \frac{100 \times M_o}{1} & = & \frac{8.8 \times 0.02}{4}
 \end{array}$$

$$\begin{aligned}
 \Rightarrow M_o &= \frac{8.8 \times 0.02}{4 \times 100} \\
 &= 4.4 \times 10^{-4} \text{ moles/L} \\
 &= 4.4 \times 10^{-4} \times 32 \text{ g/L (Rel molecular mass O}_2 = 32) \\
 &= 0.01408 \text{ g/L} \\
 &= 0.01408 \times 1000 \text{ mg/L} \\
 &= 14.08 \text{ mg/L} \\
 &= 14.08 \text{ p.p.m.}
 \end{aligned}$$

Answer: Dissolved oxygen = 14.08 p.p.m.

**19.9**

Given:-

$$V_o = 150 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 21.7 \text{ cm}^3$$

$$M_r = 0.01 \text{ M}$$

$$n_r = 4$$

$$\begin{array}{ccc}
 \text{O}_2 & & \text{S}_2\text{O}_3^{2-} \\
 \\
 \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_r}{n_r} \\
 \\
 \frac{150 \times M_o}{1} & = & \frac{21.7 \times 0.01}{4}
 \end{array}$$

$$\begin{aligned}
 \Rightarrow M_o &= \frac{21.7 \times 0.01}{4 \times 150} \\
 &= 3.62 \times 10^{-4} \text{ moles/L} \\
 &= 3.62 \times 10^{-4} \times 32 \text{ g/L (Rel molecular mass O}_2 = 32) \\
 &= 0.01158 \text{ g/L} \\
 &= 0.01158 \times 1000 \text{ mg/L} \\
 &= 11.58 \text{ mg/L} \\
 &= 11.58 \text{ p.p.m.}
 \end{aligned}$$

Answer: Dissolved oxygen = 11.58 p.p.m.

**19.10**

Given:-

$$V_o = 300 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 14.7 \text{ cm}^3$$

$$M_r = 0.02 \text{ M}$$

$$n_r = 4$$

$$\begin{array}{ccc} \text{O}_2 & & \text{S}_2\text{O}_3^{2-} \\ \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_r}{n_r} \\ \frac{300 \times M_o}{1} & = & \frac{14.7 \times 0.02}{4} \end{array}$$

$$\begin{aligned} \Rightarrow M_o &= \frac{14.7 \times 0.02}{4 \times 300} \\ &= 2.45 \times 10^{-4} \text{ moles/L} \\ &= 2.45 \times 10^{-4} \times 32 \text{ g/L (Rel molecular mass O}_2 = 32) \\ &= 7.84 \times 10^{-3} \text{ g/L} \\ &= 7.84 \times 10^{-3} \times 1000 \text{ mg/L} \\ &= 7.84 \text{ mg/L} \\ &= 7.84 \text{ p.p.m.} \end{aligned}$$

**After 5 days**

Given:-

$$V_o = 300 \text{ cm}^3$$

$$M_o = ?$$

$$n_o = 1$$

$$V_r = 4.8 \text{ cm}^3$$

$$M_r = 0.02 \text{ M}$$

$$n_r = 4$$

$$\begin{array}{ccc} \text{O}_2 & & \text{S}_2\text{O}_3^{2-} \\ \frac{V_o \times M_o}{n_o} & = & \frac{V_r \times M_r}{n_r} \\ \frac{300 \times M_o}{1} & = & \frac{4.8 \times 0.02}{4} \end{array}$$

$$\begin{aligned} \Rightarrow M_o &= \frac{4.8 \times 0.02}{4 \times 300} \\ &= 8 \times 10^{-5} \text{ moles/L} \\ &= 8 \times 10^{-5} \times 32 \text{ g/L (Rel molecular mass O}_2 = 32) \\ &= 2.56 \times 10^{-3} \text{ g/L} \\ &= 2.56 \times 10^{-3} \times 1000 \text{ mg/L} \\ &= 2.56 \text{ mg/L} \\ &= 2.56 \text{ p.p.m.} \end{aligned}$$

$$\text{B.O.D. in diluted sample} = 7.84 - 2.56 = 5.28$$

But since the original water sample was diluted twenty times

$$\Rightarrow \text{B.O.D. of original water sample} = 5.28 \times 20 = 105.6 \text{ p.p.m.}$$

Answer: B.O.D.= 105.6 p.p.m.

## Chapter 21 – Fuels and Heats of Reaction

### 21.12

Mass of solution = 500 g = 0.5 kg

Temperature rise = 18.2 – 14.8 = 3.4 °C

Specific heat capacity = 4,060 J kg<sup>-1</sup> K<sup>-1</sup>

Heat liberated = mass × specific heat capacity × temp. rise

$$= 0.5 \times 4,060 \times 3.4$$

$$= 6,902 \text{ J}$$

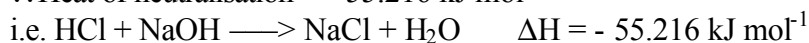
$$\text{Number of moles of HCl neutralised} = \frac{\text{volume} \times \text{molarity}}{1000} = \frac{250 \times 0.5}{1000} = 0.125$$

i.e. 0.125 mole HCl neutralised liberates 6,902 J

$$\Rightarrow 1 \text{ mole HCl neutralised liberates } \frac{6,902}{0.125} = 55,216 \text{ J}$$

Since for HCl, 1 mole of acid gives 1 mole of H<sup>+</sup> ions

∴ Heat of neutralisation = - 55.216 kJ mol<sup>-1</sup>



Answer: Heat of neutralisation = - 55.216 kJ mol<sup>-1</sup>

### 21.13

Mass of solution = 200 g = 0.2 kg

Temperature rise = 6.8 °C

Specific heat capacity = 4,200 J kg<sup>-1</sup> K<sup>-1</sup>

Heat liberated = mass × specific heat capacity × temp. rise

$$= 0.2 \times 4,200 \times 6.8$$

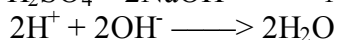
$$= 5,712 \text{ J}$$

$$\text{Number of moles of H}_2\text{SO}_4 \text{ neutralised} = \frac{\text{volume} \times \text{molarity}}{1000} = \frac{100 \times 0.5}{1000} = 0.05$$

i.e. 0.05 mole H<sub>2</sub>SO<sub>4</sub> neutralised liberates 5,712 J

$$\Rightarrow 1 \text{ mole H}_2\text{SO}_4 \text{ neutralised liberates } \frac{5,712}{0.05} = 114,240 \text{ J}$$

$$= 114.24 \text{ kJ}$$



Since, by definition, heat of neutralisation involves just 1 mole of H<sup>+</sup> ions reacting with 1 mole of OH<sup>-</sup> ions to form 1 mole of H<sub>2</sub>O

$$\Rightarrow \text{Heat of neutralisation} = \frac{-114.24}{2} = -57.12 \text{ kJ mol}^{-1} \quad \Delta H = -57.12 \text{ kJ mol}^{-1}$$

Answer: Heat of neutralisation =  $-57.12 \text{ kJ mol}^{-1}$

### 21.14

Heat of neutralisation =  $-57.2 \text{ kJ mol}^{-1}$  i.e. 1 mole HCl neutralised liberates 57,200 J

$$\text{Number of moles of HCl neutralised} = \frac{\text{volume} \times \text{molarity}}{1000} = \frac{50 \times 1}{1000} = 0.05$$

$\Rightarrow$  0.05 mole HCl neutralised liberates  $0.05 \times 57,200 = 2,860 \text{ J}$

Mass of solution =  $100 \text{ g} = 0.1 \text{ kg}$

Temperature rise = ?

Specific heat capacity =  $4,200 \text{ J kg}^{-1} \text{ K}$

Heat liberated =  $2,860 \text{ J}$

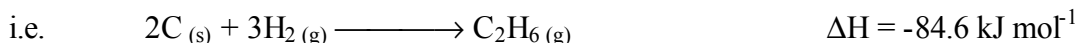
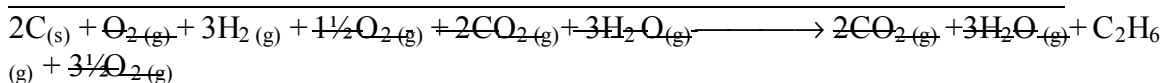
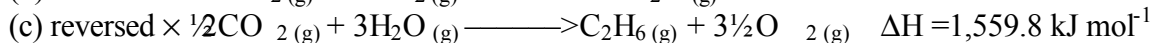
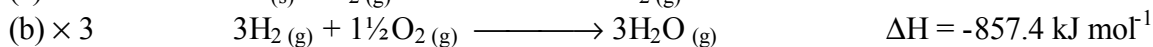
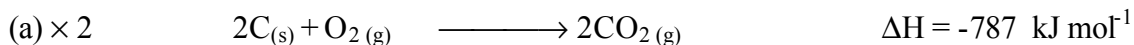
Heat liberated = mass  $\times$  specific heat capacity  $\times$  temp. rise

$$\begin{aligned} \Rightarrow \text{Temp. rise} &= \frac{\text{Heat liberated}}{\text{mass} \times \text{specific heat capacity}} \\ &= \frac{2,860}{0.1 \times 4,200} = 6.81 \text{ }^\circ\text{C} \end{aligned}$$

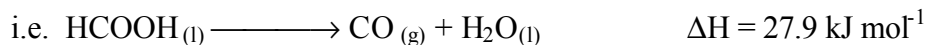
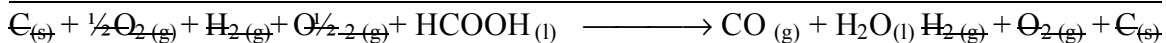
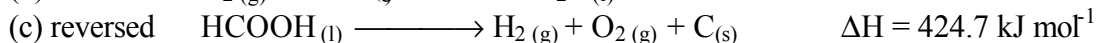
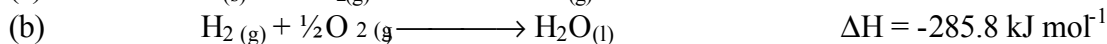
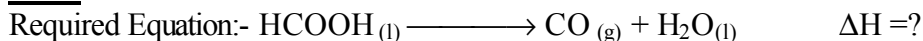
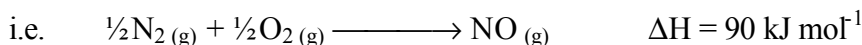
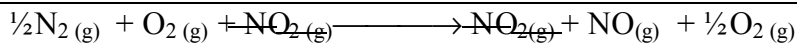
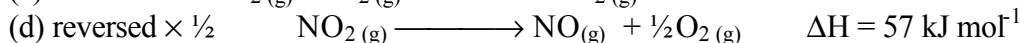
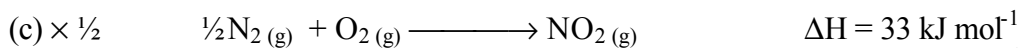
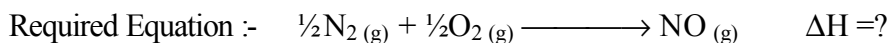
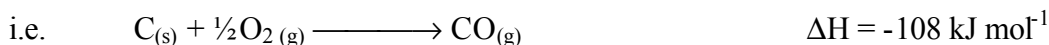
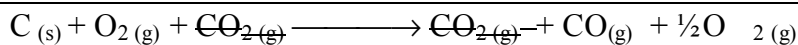
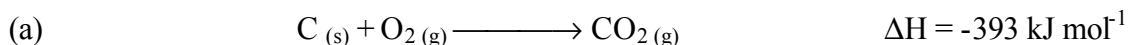
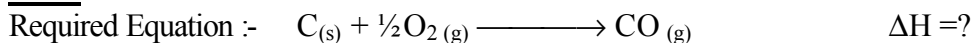
Answer: Temperature rise =  $6.81 \text{ }^\circ\text{C}$

### 21.15

Required Equation:  $2\text{C}_{(s)} + 3\text{H}_{2(g)} \longrightarrow \text{C}_2\text{H}_6(g) \quad \Delta H = ?$



Answer:  $\Delta H = -84.6 \text{ kJ mol}^{-1}$

**21.16**

 Answer:  $\Delta H = 27.9 \text{ kJ mol}^{-1}$ 
**21.17**

 Answer: Carbon monoxide:  $\Delta H = -108 \text{ kJ mol}^{-1}$ 

 Nitrogen monoxide:  $\Delta H = 90 \text{ kJ mol}^{-1}$

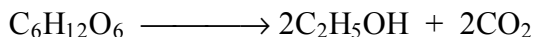
## Chapter 24 - Stoichiometry II

### 24.1

Relative molecular mass  $C_6H_{12}O_6 = 6(12) + 12(1) + 6(16) = 180$

Relative molecular mass  $C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46$

$$\text{Number of moles of } C_6H_{12}O_6 = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{20}{180} = 0.11$$



1 mole  $\longrightarrow$  2 moles

$$\begin{aligned} \Rightarrow 0.11 \text{ mole} &\longrightarrow 0.11 \times 2 \text{ mole} \\ &= 0.22 \text{ mole} \\ &= 0.22 \times 46 \\ &= 10.12 \text{ g} \end{aligned}$$

i.e. the theoretical yield of ethanol is 10.12 g

$$\begin{aligned} \text{Percentage yield} &= \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100 \\ &= \frac{7.5}{10.12} \times 100 \\ &= 74.11\% \end{aligned}$$

Answer: Percentage yield of ethanol is 74.11%.

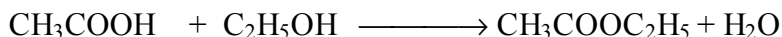
### 24.2

Assume ethanol is the limiting reagent.

Relative molecular mass  $C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46$

Relative molecular mass  $CH_3COOC_2H_5 = 12 + 3(1) + 12 + 2(16) + 2(12) + 5(1) = 88$

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{21}{46} = 0.46$$



1 mole  $\longrightarrow$  1 mole

$$\begin{aligned} \Rightarrow 0.46 \text{ moles} &\longrightarrow 0.46 \text{ moles} \\ &= 0.46 \times 88 \\ &= 40.48 \text{ g} \end{aligned}$$

i.e. the theoretical yield of ethyl ethanoate is 40.48 g

$$\text{Percentage yield} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$



$$= \frac{20}{40.48} \times 100$$

$$= 49.41\%$$

Answer: Percentage yield of ethyl ethanoate is 49% (to nearest whole number)

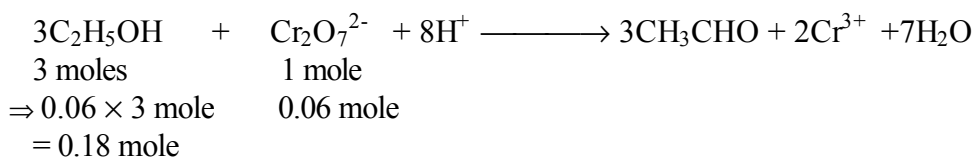
### 24.3

(i) Relative molecular mass  $C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46$

Relative molecular mass  $Na_2Cr_2O_7 \cdot 2H_2O = 2(23) + 2(52) + 7(16) + 2(18) = 298$

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{11.04}{46} = 0.24$$

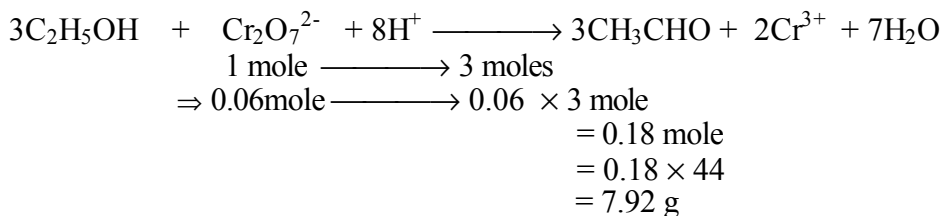
$$\text{Number of moles of sodium dichromate} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{17.88}{298} = 0.06$$



0.18 mole of ethanol would react with 0.06 mole of dichromate. However, there is 0.24 mole of ethanol present, i.e. the ethanol is present in excess.

(ii) Rel molecular mass  $CH_3CHO = 12 + 3(1) + 12 + 1 + 16 = 44$

The dichromate is the limiting reactant, so we calculate the percentage yield of ethanal on the amount of dichromate present.



i.e. the theoretical yield of ethanal is 7.92 g

$$\text{Percentage yield} = \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100$$

$$= \frac{2.97}{7.92} \times 100$$

$$= 37.5\%$$

Answer: (i) The ethanol is in excess.

(ii) Percentage yield of ethanal is 37.5%.

**24.4**

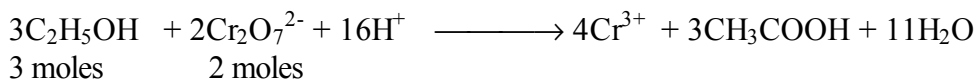
(i) Relative molecular mass  $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O} = 2(23) + 2(52) + 7(16) + 2(18) = 298$

Relative molecular mass  $\text{C}_2\text{H}_5\text{OH} = 2(12) + 5(1) + 16 + 1 = 46$

$$\text{Number of moles of sodium dichromate} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{29.8}{298} = 0.1$$

Mass of ethanol = Density  $\times$  Volume =  $0.8 \times 6.9 = 5.52$  g

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{5.52}{46} = 0.12$$



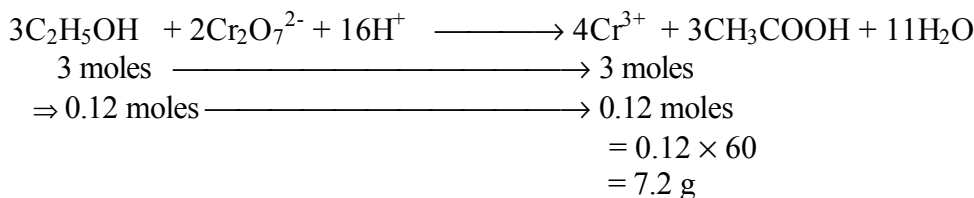
i.e. 1 mole of ethanol reacts with  $\frac{2}{3}$  mole of dichromate.

$\Rightarrow$  0.12 mole of ethanol reacts with  $\frac{2}{3} \times 0.12 = 0.08$  mole of dichromate

i.e. 0.08 mole of dichromate would react with 0.12 mole of ethanol. However, there is 0.1 mole of dichromate present. Therefore, the dichromate is present in excess.

(ii) Relative molecular mass  $\text{CH}_3\text{COOH} = 12 + 3(1) + 12 + 2(16) + 1 = 60$

The ethanol is the limiting reactant, so we calculate the percentage yield of ethanoic acid on the amount of ethanol present.



i.e. the theoretical mass of ethanoic acid is 7.2 g

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

$$\Rightarrow \text{Mass} = \text{Density} \times \text{Volume}$$

$$= 1.06 \times 5.4 = 5.724 \text{ g (actual mass of ethanoic acid)}$$

$$\begin{aligned} \text{Percentage yield} &= \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100 \\ &= \frac{5.724}{7.2} \times 100 \\ &= 79.5\% \end{aligned}$$

Answer : (i) The sodium dichromate is in excess.

(ii) Percentage yield of ethanoic acid is 79.5%.

**24.5**

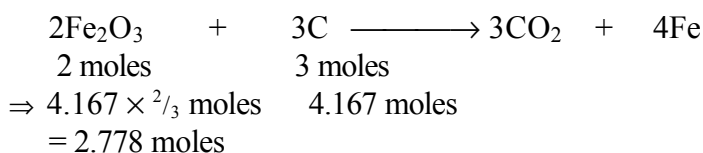
Relative molecular mass  $\text{Fe}_2\text{O}_3 = 2(56) + 3(16) = 160$

Relative atomic mass C = 12

Relative atomic mass Fe = 56

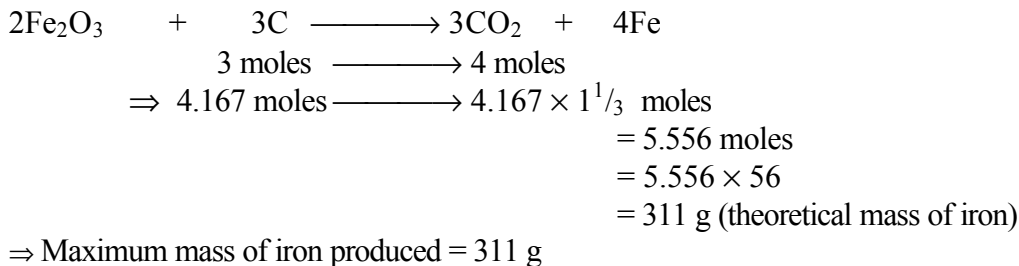
$$\text{Number of moles of iron (III) oxide} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{500}{160} = 3.125$$

$$\text{Number of moles of carbon} = \frac{\text{Mass}}{\text{Rel atomic mass}} = \frac{50}{12} = 4.167$$



2.778 moles of iron (III) oxide would react with 4.167 moles of carbon. However, there is 3.125 moles of iron (III) oxide present, i.e. the iron (III) oxide is present in excess.

The carbon is the limiting reactant, so we calculate the maximum mass of iron obtainable on the amount of carbon present.



Answer: Maximum mass of iron obtainable = 311 g .

**24.6****(a)** Calculation of percentage yield of ethanal

$$\text{Relative molecular mass Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O} = 2(23) + 2(52) + 7(16) + 2(18) = 298$$

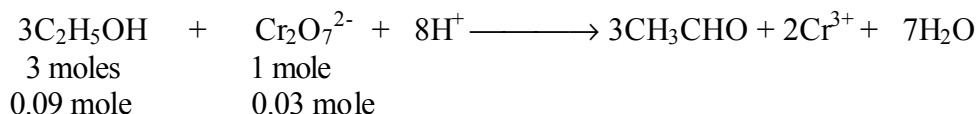
$$\text{Relative molecular mass C}_2\text{H}_5\text{OH} = 2(12) + 5(1) + 16 + 1 = 46$$

$$\text{Relative molecular mass CH}_3\text{CHO} = 12 + 3(1) + 12 + 1 + 16 = 44$$

$$\text{Number of moles of sodium dichromate} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{8.94}{298} = 0.03$$

$$\text{Mass of ethanol} = \text{Density} \times \text{Volume} = 0.8 \times 6.9 = 5.52 \text{ g}$$

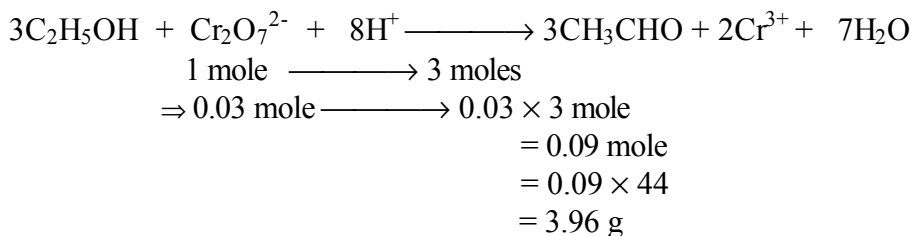
$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{5.52}{46} = 0.12$$



From the balanced equation, 1 mole of dichromate reacts with 3 moles of ethanol. Therefore, 0.03 mole of dichromate would react with  $3 \times 0.03 = 0.09$  mole of ethanol.

However, there is 0.12 mole of ethanol present, i.e. the ethanol is present in excess. In other words, the sodium dichromate is present in limiting amount.

Since the sodium dichromate is the limiting reactant, we calculate the percentage yield of ethanal on the amount of sodium dichromate present.



i.e. the theoretical yield of ethanal is 3.96 g

$$\begin{aligned} \text{Percentage yield of ethanal} &= \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100 \\ &= \frac{1.62}{3.96} \times 100 \\ &= 40.91\% \end{aligned}$$

**(b)** Calculation of percentage yield of ethanoic acid

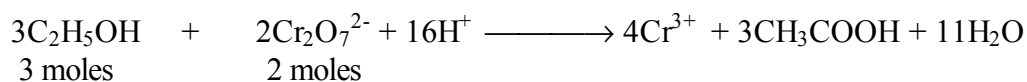
$$\text{Relative molecular mass } C_2H_5OH = 2(12) + 5(1) + 16 + 1 = 46$$

$$\text{Relative molecular mass } CH_3COOH = 12 + 3(1) + 12 + 2(16) + 1 = 60$$

$$\text{Mass of ethanol} = \text{Density} \times \text{Volume} = 0.8 \times 2.3 = 1.84 \text{ g}$$

$$\text{Number of moles of ethanol} = \frac{\text{Mass}}{\text{Rel molecular mass}} = \frac{1.84}{46} = 0.04$$

Number of moles of sodium dichromate [as calculated in part (a)] = 0.03



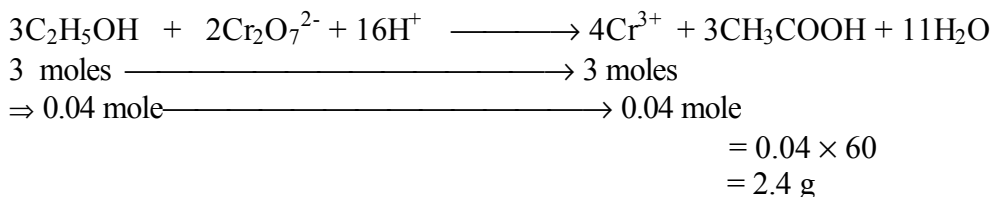
i.e. 1 mole of ethanol reacts with  $\frac{2}{3}$  mole of dichromate

Therefore, 0.04 mole of ethanol reacts with  $\frac{2}{3} \times 0.04 = 0.027$  mole of dichromate

i.e. 0.04 mole of ethanol would react with 0.027 mole of dichromate.

However, there is 0.03 mole of dichromate present. Therefore, the dichromate is present in excess, i.e. the ethanol is the limiting reactant.

Since the ethanol is the limiting reactant, we calculate the percentage yield of ethanoic acid on the amount of ethanol present.



i.e. the theoretical yield of ethanoic acid is 2.4 g

$$\begin{aligned} \text{Percentage yield of ethanoic acid} &= \frac{\text{Actual yield of product}}{\text{Theoretical yield of product}} \times 100 \\ &= \frac{1.73}{2.4} \times 100 \\ &= 72.08\% \end{aligned}$$

Answer : (a) Percentage yield of ethanal is 40.91%.

(b) Percentage yield of ethanoic acid is 72.08%.